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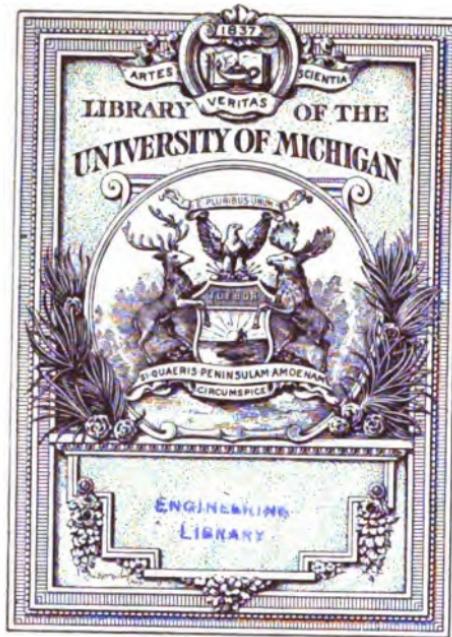
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MINUTES OF PROCEEDINGS
OF
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THE INSTITUTION
OF
CIVIL ENGINEERS;

SELECTED AND ABSTRACTED PAPERS.

VOL. CXXVIII.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. Inst. C.E., SECRETARY.

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CORRIGENDUM.

Vol. cxxvii. p. 385, line 23, for "1896" read "1897."

THE
INSTITUTION
OR
CIVIL ENGINEERS.

SESSION 1896-97.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

22 December, 1896.

JOHN WOLFE BARRY, C.B., F.R.S., President,
in the Chair.

(*Paper No. 2935.*)

“Steel Skeleton Construction in Chicago.”

By EDWARD CLAPP SHANKLAND, M. Inst. C.E.

THE main commercial district of Chicago, containing the municipal, county and government buildings, and the large offices, warehouses, hotels and theatres, occupies only $\frac{3}{4}$ square mile. This is a very small area, compared with the 186·4 square miles within the city limits. It is bounded on the north and west by the Chicago River, on the south by the net-work of railways extending to Polk Street, and on the east by Lake Michigan. These natural and artificial boundaries form obstacles to its enlargement, and the erection of many-storied buildings has become necessary in order to accommodate the great and constantly increasing demands of trade.

High buildings having become a necessity, a difficult problem was at once confronted. The soil consists of loam, and is principally made ground, to a depth of 12 feet or 14 feet, about city datum—the mean level of the lake in 1844. Below this there is a layer of blue clay, called “hard pan,” between 6 feet and 10 feet in thickness, overlying a very soft and saturated clay, which becomes harder again at a depth of 50 feet or 60 feet. The latter sometimes contains sand- and mud-pockets, but is, for the most part, of the same nature as the hard pan, and saturated for a considerable distance below the lake-level. Rock is found at a depth of between 60 feet and 80 feet. It was found by trial that the load upon the hard pan should not exceed 4,000 lbs., and should preferably be between 3,000 lbs. and 3,500 lbs. per square foot. With such loads the buildings settle between 6 inches and 12 inches. Under the old masonry buildings, however, owing

to their heavy walls and the small area of their foundations, the pressure has been found to reach 11,200 lbs. per square foot; that method of construction was therefore rendered impossible. The settlement of these old buildings was much greater than that of the recent structures, but being constructed of wood and brick or stone they would admit of great distortion. They were built immediately after the great fire of 1871, shortly after which the level of the whole of this district was raised 4 feet. For several years steps occurred in the footway, perhaps at several places in the same block of buildings, and at such times a few inches of settlement in a building would not be noticed. By using thin outside walls of brick and terra cotta, or terra cotta alone, simply as a cover for the steel frames, and by spreading the foundations, the pressure on the clay has been greatly reduced, so that the four- and five-storey buildings now standing exert a greater pressure on the clay than do the more recently constructed high buildings.

HISTORICAL.

The Montauk block, ten storeys high, built in 1881 and 1882 from the designs of Messrs. Burnham and Root, was the first of the high buildings. Railway rails were inserted in the walls under the vaults, and this was the first occasion on which an iron and concrete footing was used. The masonry footings nearly filled the basement in the old buildings, and iron and concrete footings were used to give space in the basement for the boilers, engines, and dynamos. In 1883 and 1884 the Home Insurance building, ten storeys high, was built from the designs of Mr. W. L. B. Jenney. It was the first house in which the skeleton construction was adopted, consisting of cast-iron columns and wrought-iron floor-beams. The Rookery, eleven storeys high, designed by Messrs. Burnham and Root, was erected in 1885 and 1886 with isolated footings, but with solid masonry walls; and the Tacoma building, fourteen storeys high, by Messrs. Holabird and Roche, architects, a more complete type of the skeleton construction than any of the preceding, followed; after which the system came into general use.

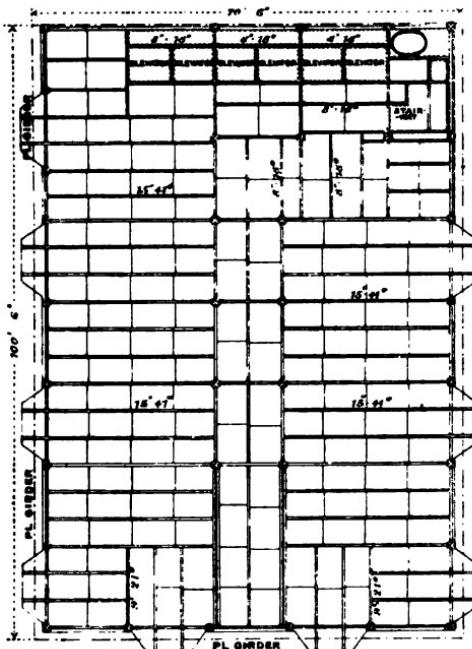
SUPERSTRUCTURE.

Before the frame of the superstructure can be designed, the positions of the columns must be determined; the architectural considerations being considered as far as is consistent with safe

design of the steel frame. A framing-plan of the roof, attic and each floor is then made, and the floor-area supported on each joist, girder and column is computed. A typical framing-plan of the Fisher building, eighteen storeys high, now being erected on Dearborn and Van Buren Streets and Plymouth Place is given in Fig. 1.

The live load, consisting of the weight of the tenants, the

Fig. 1.



Scale, 1 inch = 32 feet.

FRAMING PLAN IN THE FISHER BUILDING.

furniture and the partitions, which are frequently changed, is taken between 60 lbs. and 75 lbs. per square foot, for the upper floors of an office building, and between 75 lbs. and 100 lbs. per square foot for the first and second floors, which are generally used for shops and banks. The weight of the tenants and furniture of a typical office have been found by experiment to be only 6 lbs. or 7 lbs. per square foot; it certainly does not exceed 12 lbs. The average weight of the partitions is 25 lbs. per square

4 SHANKLAND ON STEEL SKELETON CONSTRUCTION. [Minutes of foot of floor. The dead weights of the roof and floor are calculated, those of the Fisher building being as follows:—

TABLE I.—WEIGHTS OF THE FLOOR AND ROOF OF THE FISHER BUILDING.

Floor.	Weight per Square Foot. Lbs.
½-inch maple floor	4
Deadening, cinder concrete on top of floor arch	15
15-inch hollow tile floor arch	41
Steel joists and girders.	10
Plaster on ceiling	5
Total	75
<hr/>	
Roof.	
3-inch book tile	22
6-ply tar and gravel roof	6
T-bars to support book tile	4
Steel roof framing	8
Total	40
<hr/>	

Table II, p. 5, shows how the loads are distributed in the same building.

A statement is prepared, showing the live and dead floor-loads, the weights of the outside walls, the lift loads, the weights of the lift and house-tanks, and of the water-closet floors, window-frames, glass, mullions, &c., supported on each column at each floor. The live load, except the partition load, being deducted, the remainder is used in designing the foundations. The sum of these items gives the total weight of the building. In Appendix I is shown how the loads were carried down a few of the columns of the Fisher building.

The unit stresses commonly employed are 16,000 lbs. per square inch for fibre stress in steel I beams, 15,000 lbs. per square inch for plate girders, and 15,000 lbs. per square inch for short columns in compression. In a majority of cases the columns used in a building can be considered short, as they are rigidly held at each floor. When, however, on account of high stories, or for any other reason, it becomes necessary, the unit stress is reduced by one of the standard column formulas, such as

40,000

$$1 + \frac{l^2}{36,000 r^2}; \text{ but sometimes the formula } 17,100 - 57 \frac{l}{r} \text{ is used.}$$

When loads are eccentric, the sectional area is deduced from

Rankine's formula $^1 f S = P + P_1 (1 + \frac{X_0 X_1 S}{I})$, in which P is

TABLE II.—DISTRIBUTION OF LOADS IN FISHER BUILDING.

	Load.	Joists.	Girders.	Columns.	Footings.
		Lbs.	Lbs.	Lbs.	Lbs.
Roof	Live . .	20	15	15	
	Dead . .	40	40	40	40
	Total .	60	55	55	40
Attic	Live . .	30	20	20	
	Dead . .	75	75	75	75
	Total .	105	95	95	75
Eighteenth floor to sixteenth floor.	Live . .	60	50	50	25
	Dead . .	75	75	75	75
	Total .	135	125	125	100
Fifteenth floor to thirteenth floor.	Live . .	60	50	45	25
	Dead . .	75	75	75	75
	Total .	135	125	120	100
Twelfth floor to tenth floor.	Live . .	60	50	40	25
	Dead . .	75	75	75	75
	Total .	135	125	115	100
Ninth floor to seventh floor	Live . .	60	50	35	25
	Dead . .	75	75	75	75
	Total .	135	125	110	100
Sixth floor to third floor	Live . .	60	50	30	25
	Dead . .	75	75	75	75
	Total .	135	125	105	100
Second floor	Live . .	75	60	40	25
	Dead . .	75	75	75	75
	Total .	150	135	115	100
First floor	Live . .	90	75	55	25
	Dead . .	75	75	75	75
	Total .	165	150	130	100

The weights of the fireproofing round the column, and of the column itself, are added to the above column loads.

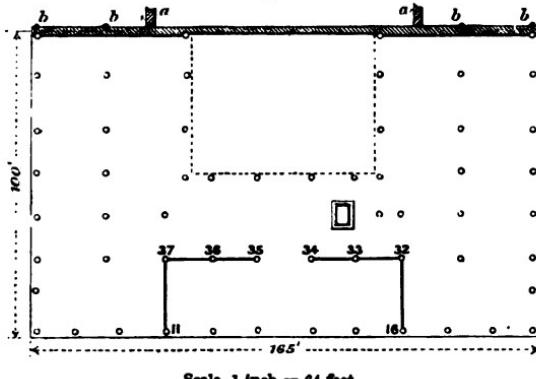
the centre load, P_1 the eccentric load, f the fibre stress, S the

¹ "Applied Mechanics," p. 305.

section required, X_0 the distance between the neutral axis and the extreme fibre, X_1 the distance between the neutral axis and the eccentric load, and I the moment of inertia of the section. This is for a short column, and is further reduced by the long column formula when necessary. Rivet shear is taken between 9,000 lbs. and 11,000 lbs. per square inch.

Steel is exclusively used in the best examples of Chicago construction. Box-columns, of plates and angle-bars, and Z-bar columns have been generally used, in which the joints of the columns have been made with a horizontal cap-plate, connected to the column by lugs. The ends of the beams or girders running to the column rested on the cap-plate with $\frac{1}{4}$ inch to $1\frac{1}{2}$ inch between the end of the beam and the face of the columns, Figs. 2, Plate 1. Columns

Fig. 4.



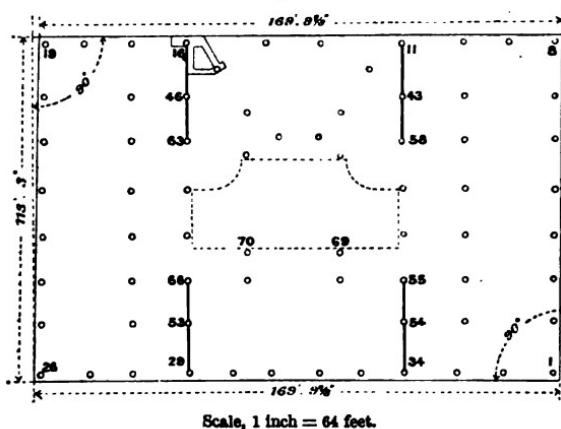
GROUND PLAN OF GREAT NORTHERN HOTEL.

made in this manner are, however, always weak laterally. Recently a column made of eight angle-bars in pairs, connected together by tie-plates, has been used. It can be kept the same size from back to back of the angle-bars, from the basement to the roof, so that the joint can be made with vertical splice-plates. The column has, Figs. 3, Plate 1, hollow spaces throughout its length, in which water-, steam-, and gas-pipes are placed. Beams and girders are connected directly with the faces of the column, a method which gives great lateral stiffness, as has been satisfactorily shown in the Reliance, Wyandotte, Fisher and other buildings. The columns are generally made in two-storey lengths, alternate columns breaking joint at the same floor.

In a building, the height of which is between four and six times

its least width, wind-pressure becomes an important element, and several methods have been used to provide for it. In the Great Northern Hotel, fourteen storeys high, and in the Masonic Temple, twenty storeys high, with a roof-garden, vertical systems of lateral rods were used, running from top to bottom of the building.

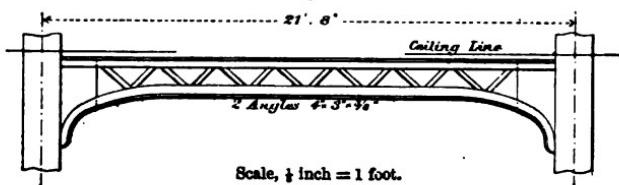
Fig. 5.



GROUND PLAN OF MASONIC TEMPLE.

similar to those in an iron pier of a railway viaduct. The ground-plan of the hotel, *Fig. 4*, shows the bracing running from column 16 to column 34, and from column 35 to column 11, forming a tower around the main entrance. A plan of the Masonic Temple, where the rods run between columns 34 and 55, 58 and 11, 29 and 66, and 63 and 16, is shown in *Fig. 5*. This method can never

Fig. 6.

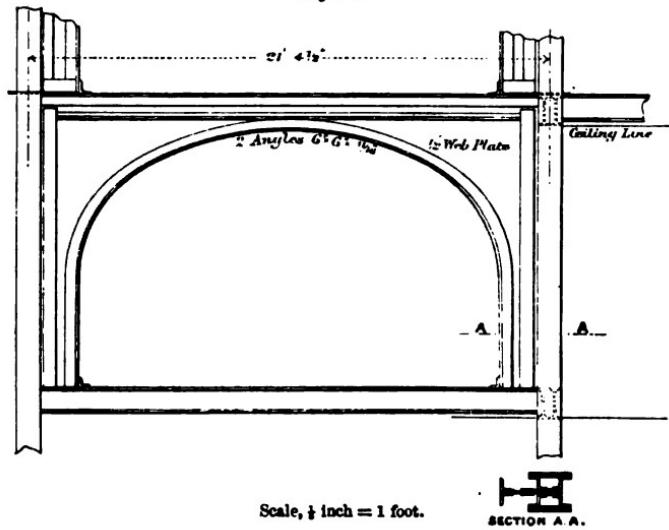


WIND BRACING, MONADNOCK BUILDING.

be carried out completely, owing to its interference with the doors and windows, and to its rendering permanent the partitions in which the systems are placed. To show that it is effective, however, the case of the hotel may be cited. The lateral rods,

which were shown in the original plans, did not arrive at the building until the frame had reached a height of five or six storeys, and the building of the outside walls had been begun. A travelling derrick was used to set the steel-work, but the vibration which it

Figs. 7.



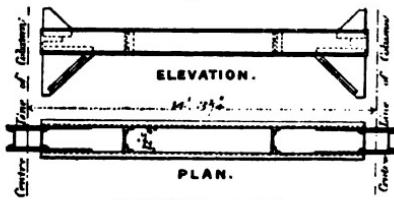
WIND BRACING, OLD COLONY BUILDING.

caused in the building made it impossible to fix the terra-cotta. Work was accordingly stopped until the rods were inserted, when there was no further trouble, although at one time the steel-work was six or seven storeys above the masonry work. Portal bracing,

between certain columns at every floor, was first used in the Monadnock building, Fig. 6, and afterwards in the Old Colony building and others, Figs. 7, but its cost is disproportionate to its effectiveness. Knee braces have been used in the New York Life and in the Fort Dearborn buildings, Figs. 8. They stiffen the framework, if carefully designed; but they require great exactness in manufacture, and care in erection.

Plate girders, 24 inches deep, running between all the outside

Figs. 8.



Scale, 1/2 inch = 1 foot.

WIND BRACING, FORT DEARBORN BUILDING.

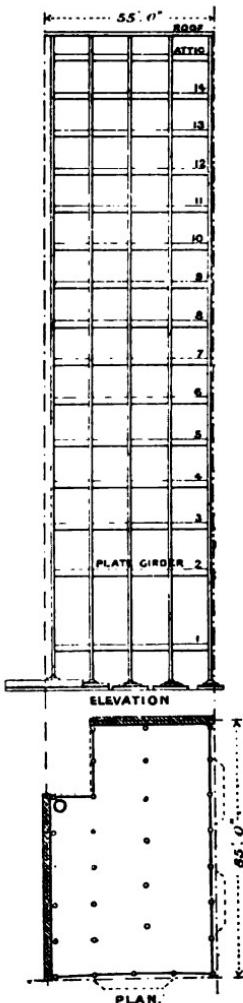
stiffen the framework, if carefully designed; but they require great exactness in manufacture, and care in erection.

columns, and rigidly connected with them, were first used in the Reliance building, 55 feet wide and 200 feet high, *Figs. 9.* The first storey of this building was slipped under the upper four storeys of the old five-storey building in 1891. In 1894 the upper four storeys were pulled down, and the new fourteen-storey building was erected from the second floor. These plate-girders, the connections of the columns by vertical instead of horizontal plates, and the bolting of the beams and girders directly to the column, instead of resting them on horizontal plates, combine to make each floor rigid in itself, and enable the wind-stresses to be carried to the ground on what may be called the "table-leg" principle.

The Author's practice is to construct the frame to withstand a horizontal wind-pressure of 30 lbs. per square foot over the whole side of the building. The resulting stresses are supposed to be taken up by all the columns in each row. If the maximum stress in any column from live, dead and wind stresses exceeds 25,000 lbs. per square inch, the column is enlarged to bring the stress below this limit. This corresponds with the maximum stress allowed for live, dead and wind stresses, in the best bridge practice—between 19,000 lbs. and 25,000 lbs. per square inch.

A typical sprandrel-section, showing the construction of the bay-window framing, is given in Fig. 10, Plate 1, and the construction between the bays is shown in Fig. 11. Fig. 12 illustrates the detail of the cornice of the Fisher building, showing how it is supported. The roof is made of beams and girders, supporting T-bars, spaced 18 inches between centres, between which book-tiles are built. Over the book-tiles is spread a layer of cement, and on this a six-ply tar-and-gravel roof is laid; the beams and girders supporting the T-bars being fireproofed. The design for carrying the balcony on

Figs. 9.

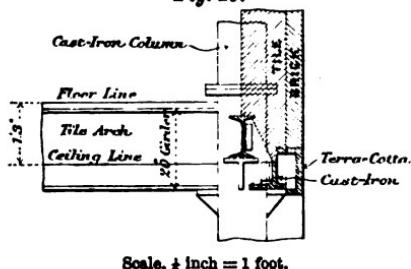


Scale, 1 inch = 64 feet.

RELIANCE BUILDING.

the front of the Mabley building, Detroit, Michigan, is given in Fig. 13, and in Fig. 14 the design of the bottom of the bays in

Fig. 16.



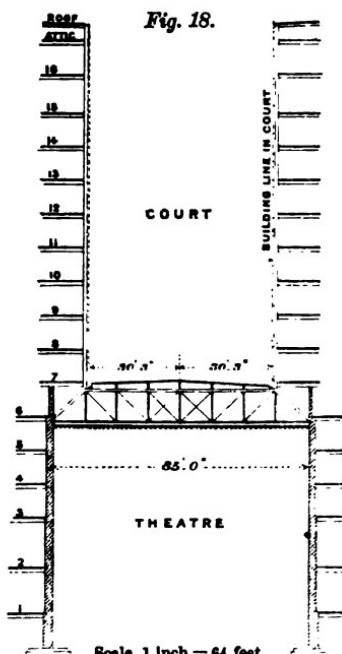
WALL SECTION, TACOMA BUILDING.

almost supplanted the old brick chimney, the first having been used in the Home Insurance building. A 2-inch air-space is left

between the steel and the brick core. The outside is of steel plates, $\frac{1}{2}$ inch to $\frac{3}{8}$ inch thick at the bottom, diminishing to $\frac{1}{4}$ inch at the top. The stack is not connected with the roof, but passes through it with a sliding joint, Fig. 15, Plate 1, so that the expansion and contraction of the stack will not crack the roof-tile.

A wall or spandrel section used in the Tacoma building, which was one of the first of the high buildings to be erected, is shown in Fig. 16. It is interesting to compare this section, used for carrying a plain brick wall, with later sections, which have to support moulded terra-cotta. Fig. 17, Plate 1, is a section through the water-closet floor of the Fisher building, showing how it is furred up, to allow the soil-pipes, &c., to run beneath. A transverse section through the Great

Fig. 18.



GREAT NORTHERN BUILDING.

Northern building, showing the roof-trusses over the theatre, is given in Fig. 18. These trusses support the columns extend-

ing to the roof, which carry the court walls in addition to the floors.

In order that a building may be absolutely fireproof, every part of the steel frame must be covered with a fire- and water-resisting material, and the outside walls must be made of brick or terra-cotta, instead of stone. Mr. J. J. Webster, M. Inst. C.E., in his Paper on "Fireproof Construction"¹ says: "There is, of course, no such thing as a fireproof structure, if the phrase is taken in a strictly literal sense, no known substance being able to resist a change of state when submitted to intense heat." This is true, but the Chicago high buildings are absolutely fireproof in the sense that they will safely resist any fire which can occur in or around them, as has been shown by severe tests to which certain buildings have been subjected. In one corner of the Rookery building there are janitors' closets, for the storage of supplies and waste paper and containing the gas-meters, one above the other, from the first to the eleventh floor. As there are no windows, the floors consist simply of iron gratings, to allow ventilation. A fire recently started in one of these closets, and in a few minutes there was a sheet of flame from bottom to top of the shaft. The gas-meters were burned, and the escaping gas aided the fire. Although it was reported by the fire brigade to be an intensely hot fire, it did no damage outside of the closets, except on one floor, where the door was opened for access to the fire. On the other floors no damage was done, even the glass transoms across the corridor being uninjured.

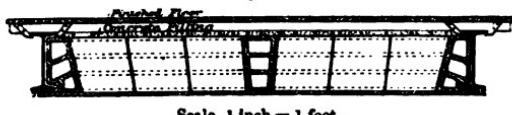
During the building of the Chicago Athletic Club, after the floors and fireproofing were erected, and while the interior was being finished, a fire occurred. About 80,000 feet of oak lumber, oiled and finished, was piled in the building ready for use, and was entirely destroyed, the damage to the building being between \$50,000 and \$60,000; but the steel frame was uninjured, with the exception of a few beams between the elevators, which buckled owing to the expansion of the iron guides fastened between them. The tile arches in the floors were uninjured. The fireproofing of the columns was destroyed, but this was through their faulty design. Wooden strips had been wedged between the flanges of the columns every 3 feet or 4 feet, and the fireproofing built between them. These strips were burned out, and the fireproofing fell to the floor.

In addition to fireproofing the beams, the floor-arches must give

¹ Minutes of Proceedings Inst. C.E., vol. cv. p. 249.

lateral stiffness to the floor. In this respect, the hard-burned fire-clay, and the porous terra-cotta lumber floor-arches, are the best hitherto devised. Numerous systems of fireproofing have been designed in recent years, nearly all of which are combinations of concrete and iron. Most of them are amply strong as to vertical loading, but none of them, as far as is known to the Author, give the requisite lateral stiffness.

The complete description of floor-arches given by Mr. Webster in the Paper¹ referred to renders it unnecessary to do more than allude to two new arches which have been introduced since that Paper was written. The end construction has been universally used in Chicago for the past four years. In *Fig. 19* is shown a

Fig. 19.Scale, $\frac{1}{4}$ inch = 1 foot.

SECTION OF 12-INCH ARCH.

12-inch arch, made by the Illinois Terra-Cotta Lumber Co. The weight of this arch is 41 lbs. per square foot for the 12-inch arch, and 34 lbs. per square foot for the 10-inch arch. A new arch, *Figs. 20*, has recently been introduced by the Pioneer Fireproof Construction Co.; it is deeper than is ordinarily made, and affords much better protection to the bottom of the beam, although it also increases the thickness of the floor.

Figs. 20.Scale, $\frac{1}{4}$ inch = 1 foot.

SECTION OF 17-INCH ARCH, SHOWING DOUBLE AIR-SPACE UNDER BEAMS.

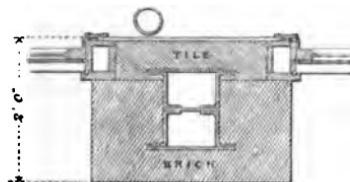
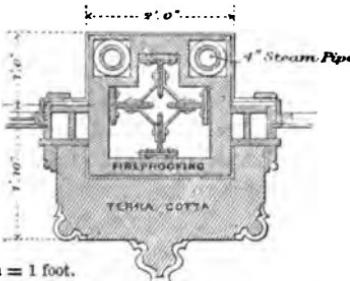
It has been the custom to place the hollow tile fireproofing on the back, and partly on the sides of the outside columns, and to trust to the brick or terra-cotta to protect the remainder, *Fig. 21*. In the Reliance and Fisher buildings the fireproofing is carried entirely round the column, *Fig. 22*, and the brick and terra-cotta front is applied outside it. It is believed that the latter

¹ Minutes of Proceedings Inst. C.E., vol. cv. p. 263 *et seq.*

method, on account of the air-spaces, affords better protection against fire, and is much more effective in preventing moisture from reaching the column.

The following is an extract from the fireproofing specification of the Reliance building: "All columns throughout the building, including the attic, shall be fireproofed with 3-inch tiles, special tiles being used having rounded corners, provided with slots to receive pipes where indicated, set plumb to a line, regularly bonded, having air-space between the fireproofing and the iron keyed in place and to each other, and each piece wired to the column with copper wire." Wherever pipes are run alongside of columns, *Fig. 22*, they are separated from the column by the fireproofing.

For preserving the steel frame from rust, the best practice is to thoroughly scrape off the scale and to apply a coat of oil at the mill or shop, and a coat of red lead, graphite or asphalt after erection. This will suffice for the beams, but additional measures are now taken to insure the safety of the columns.

*Fig. 22.**Fig. 21.*Scale, $\frac{1}{8}$ inch = 1 foot.

PLANS OF OUTSIDE COLUMNS, SHOWING FIREPROOFING.

In the Elicott Square building, being erected in Buffalo, New York, all the outside columns are filled with Portland-cement concrete, which is generally believed to be an excellent protection to iron. Mr. Eiffel has stated that in cement iron does not rust¹; and Mr. F. Collingwood has found,² from examinations at Niagara, that cement concrete affords an absolute protection to iron against rust. The steel beams used in the foundations are always completely embedded in Portland-cement concrete, and are neither oiled nor painted, as the concrete adheres more to the unpainted iron. When the fireproofing is well fixed and covered on the outside with plaster, the column is in a space nearly air-

¹ Minutes of Proceedings Inst. C.E., vol. xcvi. p. 431.² Transactions of the American Society of Civil Engineers, vol. ii. p. 337.
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tight and the danger from corrosion is small. Mr. M. P. Wood, in his Paper "Rustless Coatings for Iron and Steel,"¹ says: "In fact, for all iron and steel requiring protection from corrosion other than by the magnetic oxide processes, and that depend upon paint for their protection, it is an indispensable condition that the scale must be removed in order to secure the best result. When this is done and strictly pure red lead is mixed with pure raw linseed oil that has escaped the manipulations of the whale or menhaden oil-merchant, a paint is produced that will unite so closely to the iron or steel surface as to be only secondary in preservative qualities to magnetic oxide in resisting atmospheric effects." The use of magnetic oxide, such as in the Bower-Barff process, for the steel frame of a large building, is now prohibited by its cost, and, further, it weakens the metal. The ironwork of the tower of the new City Hall, Philadelphia, Pa., was electro-plated with copper and aluminium. To quote again from Mr. Wood:² "This process is a double one. The first one is designed to protect the iron from rust by an electro-plating of copper of 14 ounces per square foot of surface, and a finishing coat of an alloy of aluminium and tin of 2½ ounces per square foot, for colour to harmonize with the stonework of the lower storeys of the tower; also to prevent oxidation of the copper into a green coating of verdigris."

The process was adopted as a substitute for paint, the periodical renewals of which would have cost \$10,000 per annum, the principal amount being due to the use of boiling linseed oil, in which all the material was to be immersed until it had attained the temperature of the bath. The total weight of the wrought and cast iron to be protected is about 500 tons, and comprises 100,000 square feet of surface, the largest single pieces being sixteen columns, 27 feet long and 3 feet in diameter, weighing 10,000 lbs. each. These columns received the copper coating inside as well as outside. The outside coating, being most exposed, is double, requiring two operations or baths, while the aluminium coat is given last as the protective coating to all beneath it. The cost of the whole process varies between 1s. 8d. and 4s. per square foot, depending upon the shape of the piece—simple plates, rods, angles, &c., being the least, while curved pieces with large lugs, flanges with core-holes, are the most expensive. The principal expense is incurred in the cleaning, and the greatest care is necessary to ensure good work.

Mr. Henry M. Howe has advocated the attachment of zinc

¹ Transactions of the American Society of Mechanical Engineers, vol. xv. p. 1018.

² *Ibid.* vol. xv. p. 1054.

to iron structures, to oppose corrosion due to differences of electric potential. The following formula has been proposed by Prof. R. H. Thurston¹ for the probable life of steel suffering corrosion. Life, in years, = $\frac{W}{C L}$, where W is the weight of the metal in lbs. per lineal foot of the surface exposed, L the length in feet of its perimeter, and C a constant, 0.0125 for steel in air. The method of determining the value of the constant C is not given. According to this formula, a 12-inch 32-lb. I-beam will last 682 years, and a 15-inch 60-lb. bar I-beam will last 1,107 years. A column made of eight 6-inch by 3½-inch by ¼-inch L-beams will last 1,640 years, and one of eight 3½-inch by 2½-inch by ¼-inch L-beams, such as are used in the upper storeys of a building, will last 620 years.

FOUNDATIONS.

Spread foundations are used under nearly all the high buildings in Chicago. Before they are designed, borings are made to an average depth of 30 feet below the bottom of the footings, one at the site of each footing. These show whether there are any sand- or mud-pockets, and guide the determination of the load to be carried by the clay. The results obtained from a boring at the Reliance building are given in Table III, and may be regarded as typical.

In Table IV are given the results of two tests made to determine the bearing power of the soil, made in 1890 on the site of the Masonic Temple. A tank, supported on a plate having an area of 2 square feet, was gradually filled with water. In the first test the plate rested directly on the hard pan, and in the second test it was placed in the bottom of a hole 2 feet 4 inches deep in the hard pan. The foundations have in some cases been sunk into the hard pan, so as to give greater basement height. These tests show, however, that it is the safer

TABLE III.—RESULTS OF BORING AT THE RELIANCE BUILDING.

Depth. Ft. Ins.	Nature of Clay.
0 0	Arenaceous,
2 6	Compact,
7 0	Less compact,
9 6	Gradually changing into a soft and wet condition,
14 0	Somewhat harder,
15 6	Soft and wet,
31 0	Softer,
32 0	Very soft and wet,
42 0	Harder,
44 0	Very soft and wet,
51 0	Somewhat harder,
56 0	Soft and wet.
64 0	

¹ "Materials of Engineering," part ii. p. 331.

practice never to descend below the top of the hard pan. If the borings show any sand-pockets or soft spots, the contractor is required by the specification to excavate them and fill the cavity with concrete.

TABLE IV.—TESTS OF SUPPORTING-POWER OF THE SOIL ON THE MASONIC BUILDING SITE.

—	Time of Loading.	Load.	Total Settlement.
		Lbs. per Square Foot.	Inches.
Test 1 .	10th October, 10 A.M.	267·0	..
	," " 2 P.M.	2,226·5	½
	11th " 10 A.M.	4,675·5	1½
	13th " 4 P.M.	5,655·0	1½
	14th " 5 P.M.	5,655·0	1½
	18th " 4 P.M.	384·0	..
	20th " 9 A.M.	1,327·0	½
	," " 2 P.M.	2,280·0	½
Test 2 .	," " 3.30 P.M.	2,965·5	1½
	," " 4.30 P.M.	3,767·0	1½
	21st " 9 A.M.	4,311·5	1½
	," " 1 P.M.	4,984·0	2½
	," " 5 P.M.	5,627·5	2½
	24th " 7.45 P.M.	5,627·5	4½

The load per square foot having been deduced, the areas of the footings are determined. The areas of adjacent footings are often found to overlap; they are then combined as one footing, three or four being sometimes treated in this manner. In all such cases the middle of the footing is made the centre of gravity of all the loads upon it. The areas of the bottom-plates of the cast-iron shoes, or bases, upon which the columns rest, are thus derived, and the thickness of the bottom-plate and the other parts of the shoe is calculated. Under the shoes are placed layers of steel I-beams at right-angles to one another, until they cover an area 1 foot or 2 feet smaller in each direction than the required area of the footing. Under the bottom course is spread a layer of concrete between 12 inches and 16 inches thick, and covering the area required for the footing, and each layer of beams is entirely embedded in concrete. The completed footing forms a solid pyramid of steel and concrete, possessing much greater strength than if it were composed

simply of beams piled in the same manner. This increased strength is taken into account in calculating the sizes and number of the beams in the different layers. The projections of the beams in any layer are regarded as cantilevers, and the portions of the beams covered by the layer above are considered to be subject to shearing stresses only. The total load of both columns in one of the large footings of the Masonic Temple, for example, Figs. 23, Plate 1, including the weight of the masonry in both piers, is 2,750,000 lbs.; the length of the beams in the layer *l* considered is 25 feet 9 inches; and the projection *a* from the end of the beams to the centre of the outside beam in the layer above is 10 feet 6 inches.

$$\text{The bending-moment is therefore } \frac{2,750,000}{25 \cdot 75} \times \frac{10 \cdot 5^2}{2} = 5,887,000$$

foot-lbs. The layer is composed of forty-two 15-inch 60-lb. I-beams, and their total bending-moment, using a fibre-stress of 20,000 lbs. per square inch, is 6,014,400 foot-lbs. The Author uses a stress of 20,000 lbs. per square inch for foundation beams which are absolutely free from shock or vibration of any kind. It must be remembered that the load on a foundation increases very gradually. The foundations are in place several weeks before any load is applied, and it is eight or nine months before they receive their full load, so that the concrete has time to become perfectly set. The best Portland cement is used, and the greatest precautions are taken in making the concrete. In the Masonic Temple the foundation concrete was made of 1 part of Portland cement, 2 parts of clean sharp torpedo sand, and three parts of clean broken stone which would pass a $\frac{1}{2}$ -inch ring. Between the beams, crushed granite, not exceeding $\frac{1}{2}$ -inch cube, was used instead of the broken stone. As the beams must be far enough apart to allow the concrete to be filled and well rammed between them, and as the top layer is covered by the bottom plate of the cast-iron shoe, this layer can have but few beams, and they are therefore short. Each succeeding layer, being able to carry more beams, may be longer. In Fig. 24, Plate 1, is shown a footing under the Tacoma building, and in Figs. 25 a three-column footing under the Masonic Temple. A two-column footing under same building at the main entrance is given in Figs. 23; and Figs. 26 show a double-column footing under the Herald building carrying two of the front masonry piers.

The dead load only is used in designing the footings, in order to secure a more uniform settlement of the building. The amount of the settlement is of small importance, provided it is equal in all parts. If the live load were considered in the calculations, the interior footings would carry a much higher percentage of live

load, and it would be impossible for the buildings to settle uniformly. In the case of the Marshall Field warehouse in Adams Street, designed by the late H. H. Richardson, the live load of 75 lbs. per square foot, on every floor, was carried down to the footings, according to the practice in New York and Boston. The result is that all the floors have risen considerably at the centre.

For the most part, the owners of adjacent sites draw up a contract for a party wall. Sometimes, however, this is not done, and the footings along the party line have to be kept entirely within the site, necessitating the use of cantilevers. That used under the Rand and McNally building, ten storeys high, erected in 1889, is shown in Figs. 27, Plate 1. This is a very heavy building, the floors having a live load of 150 lbs. to 200 lbs. per square foot, and the 6th floor, where the printing-presses are placed, 300 lbs. The construction used in the Herald building, built in 1891, is given in Figs. 28.

Pile foundations have been very little used under office buildings, although almost invariably under the warehouses and other buildings on the banks of the river. The Art Institute, Public Library, Schiller Theatre and Stock Exchange rest on piles, 40 feet to 50 feet long, driven in accordance with standard formulas for pile-driving, and treated as bearing piles. At the Stock Exchange, in addition to the piles, wrought-iron tubes filled with concrete were sunk to a considerable depth. The latter form, however, a very expensive foundation. Pile foundations have been used for many years, and the spread foundations are perfectly safe, as the number of large buildings standing on them prove, some of which have been erected ten or twelve years.

In the Fisher building piles were employed, but the principle involved in their use is entirely different from that referred to, for they are essentially spread foundations. On account of the absence of a party-wall contract, it was found impossible to use the ordinary spread footings along the party line. The Author considered that by driving short piles the clay would be compressed, and would be in the same condition before the building was commenced as it ordinarily assumes after a heavy building has been erected upon it. The clay would therefore stand a greater load than would otherwise be considered safe. Accordingly piles 25 feet long were driven at 3 feet between centres. The load for each pile was 25 tons, the 9 square feet of clay around each pile being loaded to nearly 6,000 lbs. per square foot the pile being disregarded. The piles, however, will act with the clay in bearing the load, for it required between four and eight

blows with a 2,500-lb. hammer falling 20 feet or 24 feet to drive the piles down the last foot. A footing of this building carrying two columns and the steel stack, is shown in Figs. 29, Plate 1; and Fig. 30 illustrates a single column-footing under the same building.

A foundation designed by the Author for an office building now being erected in Washington Street is shown in Fig. 31. The building, which will be eleven storeys high, is 40 feet wide by 165 feet long, and is between two buildings, one four, the other seven storeys high. The walls on both sides had formerly been party walls, but new contracts had not been obtained, so the footings had to be kept entirely within the site, the boundaries being the middle of the existing walls. To shore up these walls and carry the foundations to the boundaries, would have been a costly and somewhat hazardous operation, as the footings would occur close together along the walls, and would penetrate considerably deeper than one wall. The plan adopted allowed piles to be driven along the centre of the lot, parallel to the walls, with a minimum distance from both walls of 6 feet. On the top of each row of piles a plate girder was placed, upon which the four columns occurring in the width of the building rest. Piles were used in the same manner as in the Fisher building, the tops of the piles being embedded in concrete instead of using a timber grillage.

In the Great Northern theatre, hotel and office building, in course of erection on the east side of the Great Northern hotel, in Jackson Street, the theatre is in the middle of the building. Heavy walls separate it from the office and hotel portions. These walls, each weighing, with the floor loads, 60,000 lbs. per lineal foot, meet the east wall of the present Great Northern hotel at right angles. This east wall had been originally regarded as a party wall, and its footing had been constructed strong enough to carry a floor load from each side. The end of the theatre wall where it meets the east wall could not rest on the footing of the latter, which projects 9 feet 6 inches, as it would overload the footing, besides being only on one side. The old building had practically stopped settling, and the new one would probably settle 7 inches or 8 inches. The floor load, however, from the east side had never been put upon this footing, and in addition it was deemed safe to load it somewhat higher than formerly, as the east wall, fourteen storeys high, had been resting upon it for four years. Plate girders, Figs. 32, Plate 1, were placed lengthwise in the theatre wall, with their ends projecting through

the old wall, and resting on 36-ton hydraulic jack-screws, which in turn were supported by I-beams lying on the footing and parallel to the old wall. The plate girders were of such a length, and so situated, as to transfer to the old footing the desired weight. The screws were raised to their full height, so that they could be lowered 14 inches if necessary. As the new building settles these screws will be run down at regular intervals, until the settlement stops, which will probably be in four or five years. Levels will be taken during that period. After the settlement has ceased, the screws will be surrounded with concrete and left. The points dealt with are shown at *aa*, Fig. 4; the four other points, *b*, where the new building joins the old, will be treated in a similar manner.

The spread foundations of Chicago have often been referred to as floating, and the soil has been regarded as a fluid, the settlement being constant, with more or less lateral displacement. The Author does not believe that any such lateral movement exists, for it would follow the line of least resistance; and with a heavy building on each side of the street, for example, the Great Northern and Monadock, it would show itself in the disturbance of the network of pipes in the street, and in the forcing up of the pavement itself. The settlement is due to the compression of the clay, the water being pressed out of it. In the Masonic Temple four of the main columns, near the lifts, carry heavy loads and have large footings, and between them are two small columns which only carry the stairs. As these had much smaller footings than any others in the building, they were given a higher load per square foot. During the construction of the building, the four columns had received the greater portion of their loads when the erection of the stairs was begun. It was found at once, that the connections on the stairs would not fit those on the columns, the latter being too high. Levels taken to ascertain whether the small columns had been forced up, showed that they simply had not settled with the rest of the building. About 75 tons of pig-iron were then loaded on both footings, and allowed to remain for a week. Although the load then amounted to 7,000 pounds per square foot, twice the load on any of the other footings, the column only settled about 1 inch less than one-half the desired amount, and so the connections had to be changed all the way up the stairs.

The compression of the soil varies with the load, is greatest when the load is first applied, diminishes and finally stops. Curves of settlement of six columns, four at the corners of and two

within the Masonic Temple, are given in *Fig. 33.* The ground plan of the building, *Fig. 5*, gives the positions of the six columns. The levels of the two interior columns could not be taken after the 20th of October, as the old marks had been covered. These curves are rapidly approaching a horizontal line; the amount of settlement since the last levels were taken, almost two years ago, is nearly the same in each case, the maximum variation being only $\frac{1}{2}$ inch, although they had varied considerably before. The auditorium settled more than 20 inches under the tower, but this was due to the fact that several storeys were added which were not in the original design and were introduced after the foundations had been inserted. Probably none of the high buildings on spread footings settled less than 6 inches. The amount of settlement generally is between 6 inches and 12 inches. This settlement is anticipated when construction is begun, by raising the level of the bottom of the footings by the amount it is thought the buildings will settle. This causes the footways to be steep at first, but they approach their proper slope as the buildings settle. The foundations of the Great Northern theatre have been raised 9 inches.

Fig. 33.CURVES OF SETTLEMENT IN THE
MASONIC TEMPLE.

WEIGHT AND COST OF THE STEEL FRAME.

The weight of the steel frame in an office building sixteen to twenty storeys in height, ranges from $1\frac{5}{8}$ lb. to 2 lbs. per cubic foot of the building. The cost is between 4·9 cents and 6 cents per cubic foot, being one-seventh to one-ninth of the cost of the building.

PERIOD OCCUPIED IN CONSTRUCTION.

It requires between seven months and a year to erect and completely finish an office building. At the Reliance building work was begun by pulling down the upper four storeys of the old building, on the 1st May, 1894. Some delay was caused by the construction of a temporary roof over the second floor and making connection to the first storey columns. The first floor was occupied during the whole time of construction. The building was finished and tenanted on the 1st April, 1895. At the New York Life building, twelve storeys high, excavation was begun on the 14th July, 1893, and the foundation was begun on the 3rd August. The steel frame was completed on the 29th September, and on the 2nd December, steam heat was turned on to the entire building. At the Champlain building, fifteen storeys high, excavation was begun on the 12th September, 1893, and the foundation ironwork on the 10th October. Between the 15th and the 25th October work was stopped pending decision as to the party wall. On the 23rd December the ironwork was completed, and on the 4th January, 1894, the fireproofing of the floors was finished. Both these buildings were ready for tenants in the early spring of 1894.

The Author desires to acknowledge his indebtedness to Mr. D. H. Burnham for much valuable information and kindly criticism, and to Mr. W. L. B. Jenney and Mr. Wm. Holabird for data and drawings relating to the history of skeleton construction.

The Paper is accompanied by seventeen tracings and fifteen photographs, from which Plate 1 and the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.—COPY OF THE COLUMN SHEET, FISHER BUILDING.

		4-	9-12-21 10-19-22 11-20-23	28-31 29-32 30-33	34- 35-
Attic	Roof . . .	Lbs. 10,500	Lbs. 10,230	Lbs. 14,190	Lbs. 21,450
	Column and casing . . .	1,500	..	3,000	3,000
	Tanks . . .	..		
	Elevators . . .	18,000	186	253	390
18	Total . . .	30,000	10,230	17,190	24,450
	Floor . . .	11,780	17,670	24,510	37,050
	Column and casing . . .	2,440	..	4,870	4,870
	Cornice, &c. . .	78,750	30,000	253	28,900
	Tanks . . .	..	1,700		5,000
17	Total . . .	122,970	59,600	75,470	71,370
	Floor . . .	15,500	23,250	32,250	48,750
	Column and casing . . .	2,440	8,280	4,870	4,870
	Spandrel . . .	21,580	13,050		
16	Total . . .	162,490	104,130	112,590	124,990
	Floor . . .	15,500	23,250	32,250	48,750
	Column and casing . . .	2,440	8,760	4,870	4,870
	Spandrel-mullion . . .	23,000	10,320		
15	Total . . .	203,430	146,460	149,710	178,610
	Floor . . .	15,500	23,250	32,250	48,750
	Column and casing . . .	2,440	8,760	4,870	4,870
	Spandrel-mullion . . .	23,000	7,500		
14	Total . . .	244,370	185,970	186,830	232,230
	Floor . . .	14,880	24,000	30,960	46,800
	Column and casing . . .	2,440	8,760	4,870	4,870
	Spandrel-mullion . . .	23,000	7,500		
13	Total . . .	284,690	226,230	222,660	288,900
	Floor . . .	14,880	24,000	30,960	46,800
	Column and casing . . .	2,440	8,760	4,870	4,870
	Spandrel-mullion . . .	23,000	7,500		
12	Total . . .	325,010	266,490	258,490	335,570
	Floor . . .	14,880	24,000	30,960	46,800
	Column and casing . . .	2,440	8,760	4,870	4,870
	Spandrel-mullion . . .	23,000	7,500		
11	Total . . .	365,930	306,750	294,320	387,240
	Floor . . .	14,260	23,000	29,670	44,850
	Column and casing . . .	2,440	8,760	4,870	4,870
	Spandrel-mullion . . .	23,000	7,500		
10	Total . . .	405,030	346,010	328,860	436,960
	Floor . . .	14,260	23,000	29,670	44,850
	Column and casing . . .	2,440	8,760	4,870	4,870
	Spandrel-mullion . . .	23,000	7,500		
» Totals Car. For.		444,790	385,270	363,400	486,680

COLUMN SHEET, FISHER BUILDING—continued.

		4-	9-12-21 10-19-22 11-20-23	28-31 29-32 30-33	31- 35-
9	Totals Bt. For.	Lbs.	Lbs.	Lbs.	Lbs.
	Floor . . .	444,730	385,270	363,400	486,680
	Column and casing . . .	14,260	23,000	29,670	44,850
	Spandrel-mullion . . .	2,440	8,760	4,870	4,870
8	Elevator . . .	12,780	7,500		
	Total . . .	37,800			
	Floor . . .	512,010	424,530	397,940	536,400
	Column and casing . . .	13,640	22,000	28,380	42,900
7	Spandrel-mullion . . .	2,440	8,760	4,870	4,870
	Total . . .	12,780	7,500		
	Floor . . .	540,870	462,790	431,190	584,170
	Column and casing . . .	13,640	22,000	28,380	42,900
6	Spandrel-mullion . . .	2,440	8,760	4,870	4,870
	Total . . .	12,780	7,500		
	Floor . . .	569,730	501,050	464,440	631,940
	Column and casing . . .	13,640	22,000	28,380	42,900
5	Spandrel-mullion . . .	2,540	8,760	5,070	5,070
	Total . . .	12,360	7,500		
	Floor . . .	598,270	539,310	497,890	679,910
	Column and casing . . .	13,020	21,000	27,090	40,950
4	Spandrel-mullion . . .	2,540	9,120	5,070	5,070
	Total . . .	13,310	7,500		
	Floor . . .	627,140	576,930	530,050	725,980
	Column and casing . . .	13,020	21,000	27,090	40,950
3	Spandrel-mullion . . .	2,540	9,120	5,070	5,070
	Total . . .	13,310	7,500		
	Floor . . .	656,010	614,550	562,210	771,950
	Column and casing . . .	13,020	21,000	27,090	40,950
2	Spandrel-mullion . . .	2,540	9,120	5,070	5,070
	Total . . .	13,310	7,500		
	Floor . . .	684,880	652,170	594,370	817,970
	Column and casing . . .	13,020	21,000	27,090	40,950
1	Spandrel-mullion . . .	3,240	9,120	6,670	6,670
	Total . . .	9,950	12,240	238	
	Floor . . .	711,090	694,530	628,180	865,590
	Column and casing . . .	14,260	21,390	29,670	44,850
Base- ment	Spandrel-mullion . . .	2,840	12,000	5,670	5,670
	Total . . .	19,600	8,820	258	890
	Floor . . .	747,790	736,740	663,470	916,110
	Column . . .	16,120	24,180	33,540	50,700
Foot- ing	Sidewalk . . .	2,000	10,200	4,000	4,000
	Party wall . . .	124	10,660		
	Total . . .	26,780			
	Live load (deduct)	792,690	781,780	701,010	970,810
Footing		34,100	51,150	70,950	107,250
	Footing . . .	758,590	730,630	630,060	863,560

APPENDIX II.

MESSES. D. H. BURNHAM & COMPANY'S SPECIFICATION FOR MATERIAL AND WORKMANSHIP.

Material and Workmanship.—All field connections must be bolted; all field holes must be reamed. All bolts must be perfectly round, either cold rolled or turned, and must be $\frac{1}{2}$ inch smaller than the holes receiving them.

Columns.—Columns are to be made in two-storey lengths, alternate columns being jointed at each storey. Sections of material are to be as designated on the drawings. The quality of material to be as hereinafter specified. The column splice is to come above the floor as shown on drawings.

No cap-plates are to be used, and the ends of each column must be faced off at right angles to the longitudinal axis, using the greatest care to make the work exact.

Columns must be connected to those above by vertical splice-plates, the sizes of which, and the number of rivets for each splice, are shown on the drawings.

The holes for splice-plates at the bottom of the column must be punched $\frac{1}{8}$ inch small. After the plates are riveted to the column, the column next above shall be set in place and the holes reamed, using the splice-plates as templates. The connection of girders or joists to the columns shall be standard where the girders or joists are at right angles to the connecting face of the column. A special or typical detail for oblique connections will be as shown on the drawings.

Quality of Material.—The steel may be made either by the Bessemer or open-hearth process. It must be uniform in quality and must not contain over 0.10 per cent. of phosphorus. The steel shall have an ultimate strength of 60,000 lbs. per square inch, and shall not vary from this more than 4,000 lbs. per square inch either way. It shall have an elastic limit of not less than one-half the ultimate strength; an elongation of not less than 25 per cent. in 8 inches and a reduction of area of not less than 45 per cent. at point of fracture.

All blooms, billets, or slabs shall be examined for surface-defects, flaws, or blow-holes, before rolling into finished sections, and such chipping and alterations made as will ensure perfect solidity in the rolled sections.

A test from the finished material will be required, representing each blow or cast; in case the blows or casts from which the blooms, slabs or billets, in any reheating furnace charge are taken, have been tested, a test representing the furnace-heat will be required, and must conform to the requirements heretofore enumerated.

A duplicate test-piece from each blow or cast and furnace-heat will be required, and it must stand cold bending 180° over a mandrel, the diameter of which is equal to one and one-half times the original thickness of the specimen, without showing sign of rupture on either convex or concave side of curve.

After being heated to a dark cherry and quenched in water 180° F. it must stand bending as before.

The original blow or cast number must be stamped on each ingot from said blow or cast, and this same number, together with the furnace-heat number, must be stamped on each piece of finished material from said blow, cast or furnace-heat.

No steel, beam or angle shall be heated in a forge or other fire after being rolled, but shall be worked cold, unless subsequently annealed.

Rivet Steel.—Steel for rivets throughout this structure shall have an ultimate tensile strength of not less than 56,000 lbs., nor more than 62,000 lbs. per square

inch, an elastic limit of not less than 30,000 lbs. per square inch, an elongation of not less than 25 per cent. in 8 inches, and a reduction of area at point of fracture at least 50 per cent.

Specimens from the original bar must stand cold bending 180° and close down on themselves without sign of fracture on convex side or curve. Specimens must stand cold hammering to one-third of their original thickness without flanging or cracking, and stand quenching as heretofore specified for rolled specimens.

Wrought-Iron.—Where wrought-iron is required by plans and specifications it shall be tough, fibrous, and uniform in quality, and shall have an elastic limit of not less than 26,000 lbs. per square inch. It shall be thoroughly welded during the rolling, and free from injurious seams, blisters, buckles, cinders, or imperfect edges.

When tested in small specimens the iron in no case shall show an ultimate tensile strength of less than 50,000 lbs. per square inch, and shall elongate 18 per cent. in 8 inches.

The same sized specimens taken from angle and other shaped iron shall have an ultimate strength of not less than 50,000 lbs. per square inch, and shall elongate 15 per cent. in 8 inches.

All iron and specimens from plate, angle and shape iron, must bend cold for about 90° to a curve whose diameter is not over twice the thickness of the piece without showing fracture.

When nicked on one side and bent by a blow from a sledge, the fracture must be nearly all fibrous, showing but few crystalline specks.

Cast-Iron.—Cast-iron shall be the best quality of metal for the purpose. Castings shall be clean and free from defects of every kind, boldly filleted at the angles, and with arrises sharp and perfect.

Cast-iron must stand the following test: A bar 1 inch square, 5 feet long, 4 feet 6 inches between bearings, shall support a centre load of 550 lbs. without sign of fracture.

Punching and Reaming.—In all work the diameter of the punch shall not exceed by more than $\frac{1}{16}$ inch the diameter of the rivets to be used. Rivet-holes must be accurately spaced; the use of drift pins will not be allowed except for bringing together the several parts forming a member, and they must not be driven with such force as to distort the metal about the holes. If the holes must be enlarged to admit the rivet, they must be reamed.

Riveting and Punching.—All rivets will be steel. All rivets in this work must be accurately spaced, so that upon the assembling of adjacent pieces a cold rivet of the size intended for the work can be inserted in holes.

Drifting, when found to injure, will not be allowed.

Rivets with crooked heads, or heads not centrally located on the shaft, or loose under the heads or in their length, must be cut out.

All rivet-holes must be so accurately punched that when several parts forming one member are assembled together a rivet $\frac{1}{16}$ inch less in diameter than the hole can enter hot without reaming, drawing, or straining the iron by drifts.

The rivets when driven must completely fill the holes.

The rivet-heads must be hemispherical and of uniform size for the same size rivets throughout the work. They must be full and neatly formed, and be concentric with the rivet-holes. Wherever possible all rivets must be machine-driven.

So far as possible all rivets shall be driven by direct-acting power machines, which are capable of holding on to the rivets after upsetting is completed. When it is found necessary to cut out rivets in steel-work, it shall be done in a way not to injure the material.

Painting.—Iron-work for foundations shall not be oiled or painted; all other material before leaving the shop or mill shall have all new scales scraped off, and be thoroughly coated with the best boiled linseed oil well rubbed in.

In all riveted work surfaces not accessible after assembling must receive two coats of red lead paint, as specified below, before assembling. All finished surfaces to receive one coat of white lead and tallow.

After iron-work is erected, the contractor shall give it one coat of paint, composed of red lead, of a quality approved by the architects, and the best boiled linseed oil.

Inspection and Testing.—All finished material will be given a thorough surface-inspection, and it must be perfectly straight, clean, smooth and free from flaws, cracks, cinder-pockets.

The contractor shall furnish without charge full and ample means for the inspection and testing of all rolled, forged or cast material for this work. He shall furnish without charge such prepared specimens of the several kinds of iron to be used as may be required to determine their character, and shall admit the architects or their authorized inspectors to any portion of the mill or shop where work is being done under this contract.

Full size members must be tested at the option of the architects, but if tested to destruction and proven satisfactory, such material shall be paid for at cost, less its scrap value. If it does not stand the specified tests, it will be rejected material, and be solely at the cost of the contractor.

The contractor shall furnish the use of a testing-machine capable of testing the specimen free of charge.

The inspection will be made as soon as possible after the material is cut to lengths and ready for shipment, and all material must be shipped from rolling-mill as soon as possible after inspection. Should any delay occur in shipment of material after inspection, it shall be so piled up in manner and place as not to be injured by rust or otherwise.

The acceptance of material by inspectors will not be considered final, but the right is reserved to reject any material which may prove defective or objectionable, at any time before the completion of this contract, and all damage done to other work by the removal of faulty iron or steel must be made good by the contractor.

Discussion.

Mr. Wolfe Mr. J. WOLFE BARRY, C.B., President, had the pleasing duty to Barry. move a cordial vote of thanks to the Author for his valuable contribution to the Proceedings. The members would all recognize in the Paper the extreme ingenuity which their American brethren had shown in adapting the form of buildings to the special requirements of the locality. They could also form a good judgment from the interesting lantern slides exhibited, of the extraordinary speed with which those buildings had been erected, and of the extreme care which must have been taken in the preparation of the designs to admit of such rapid building being possible. Of course, the mere spreading of foundations to suit the special requirements of the soil of any locality was neither new nor unusual in the experience of engineers and architects in this or in any other country. He, himself, at the Barry Docks, had to grapple with precisely the same condition of things, having had to build some massive and lofty towers for the shipping of coal, the total height of which was not far short of 100 feet. These had to be built upon mud which was extremely soft and had a depth of 40 feet or 50 feet below the foundations. In that case, before proceeding to deal with the problem, a number of experiments were made with regard to the supporting power of the mud, and after the gradual application of smaller loads had occasioned definite subsidences proportional to the loads applied, it was found that 2 tons on the square foot produced a movement of the test-loads almost similar to their sinking in a viscous fluid, not merely a gradual compression of the soil, but a sudden disappearance of all resisting power. He was thus not prepared to agree with one of the statements in the Paper, that the resistance produced by foundations upon plastic clay was merely due to the squeezing out of water or the compression of the clay itself. In his opinion the movement of such plastic soils, when the limiting power of resistance had been reached, was much more than that of a fluid. He had himself come to that conclusion, and all the experiments he had made confirmed it. By spreading the foundations of the towers to which he had alluded over a very large base, so that in no place was there more than about 1 ton on the square foot, neither the towers nor the machinery which this supported, and which was in constant vibration and carried very considerable loads, had ever shown the slightest signs of settlement. There

was a certain small amount of compression at first of the upper surface of the clay, but after that nothing happened. He had little to add, except to recognize how very carefully everything had evidently been thought out in the buildings at Chicago which they were considering, and how much care had been taken to ensure a uniform pressure over all the parts; because, after all, it was a most important point—that there should be no particular part of those lofty buildings which would bring a greater strain upon the foundations than other parts, so that the whole might yield together. He held that every building placed upon earth settled more or less, depending upon the nature of the earth—in some cases such subsidences reached very large amounts, such as those mentioned in the Paper, and in other cases the yielding was almost inappreciable. At the great piers of the Tower Bridge, for example, it was recognized that subsidence would take place, and it was provided for. Subsidence did take place, and, speaking from memory, he thought the total settlement, which was extraordinarily regular as the weight was increased, amounted to upwards of 3 inches in each of the piers. Apart from any question of the details of the valuable Paper under consideration, it appeared to him that, regarding the public interests of a large town, such extraordinarily high buildings were not things in themselves desirable. It was a principle that could be carried much too far, looking to the general interest of those who lived in such towns apart from that of those who owned or occupied land for their individual profit. It could not, he thought, be to the real advantage of large towns that light and air should be so much excluded, or that persons should be allowed to use their land in such a way as to damage either their immediate neighbours or the community as a whole. There might, of course, be special circumstances in Chicago with which he was not acquainted that might modify that view, but he thought it was one which ought to be well considered by all who had the guardianship of such matters. He should like to ask how the terra-cotta was satisfactorily attached to the ironwork of the buildings. It must need much care to prevent any cracking, subsidence, or settlements from showing themselves in such rigid materials. He had no doubt from the expressions in the Paper that it had been done, but it was an interesting practical detail, and it was also of material importance in connection with protection of the iron or steel from fire, which was of course a point of extreme necessity in buildings of twenty storeys, even though constructed mainly of fireproof materials.

Mr. Pye-Smith. Mr. A. PYE-SMITH thought there could be no question that the requirements of the peculiar condition of things at Chicago had been admirably met. The conditions in England, fortunately, were not quite similar, certainly not in London, where it was to be hoped that there would be no necessity to erect such high buildings as those described in the Paper. One thing which had struck him was the very great weight involved in the process of preserving the metal from fire. The terra-cotta bricks or slabs used seemed to form a very large portion of the total weight of the structure; and partly on that account, and partly on account of the very excellent steel work that was made, he observed that the total cost of the skeleton structure alone came to about 3d. per cubic foot. In England it would be found rather hard to spend 3d. per cubic foot on the skeleton work, not of warehouses, but of offices, which were not required to carry very great weights. The cost of the system, therefore, seemed to preclude its use, except under certain particular circumstances. No doubt the terra-cotta protection described was efficient, but it appeared to him that it was expensive and heavy. In all the various forms of terra-cotta protection used in the United States, which were described at length in Mr. Webster's Paper, which had been referred to, it appeared to him that the greatest means of protection against fire had been ignored, namely, air; and the reason of course was that it was very difficult to get the air to act as a confined protector. But it could be done, and it had been done practically on a considerable scale. The system that he had seen adopted successfully was to suspend a fire-proof plastering below the girders and the floor and away from the columns. That could be done by a number of ingenious contrivances, and one of the things to enable it to be done was a metal webbing that would carry the plaster satisfactorily. The one referred to already answered in certain cases, namely, a sort of rabbit wire-netting, but the key of that did not seem sufficient. No doubt most of the members were well acquainted with a number of different kinds of lathing that had been used for that purpose. In the Métropole Hotel, Folkestone, the floors and all the ironwork had been covered with a netting invented by Mr. Banks, which was made with a flat steel drawn wire, twisted and then interwoven so as to leave meshes about $\frac{1}{4}$ inch square. That was so flexible that it could be wrapped around columns or put under the soffits of girders without difficulty. In the same way it might be utilized to form the core of floors or ceilings. Another point that he had noticed in the Paper was with reference to the power of Portland cement concrete

to stand against fire and water. A year or two ago he was present at a series of experiments with regard to that problem. The covers were taken off the furnaces of cement-roasting kilns, and in place of those covers slabs of different construction were put on. The general way in which they were made was to have the Banks webbing embedded in $1\frac{1}{4}$ inch or $1\frac{1}{2}$ inch plaster material. A number of different plasters were tried, and the slabs, when dry, were put over the furnace so as to take the place of the ordinary covering. Then the furnace was kept at its greatest heat about a couple of hours, and while it was still in full blast, a stream of water from a fire-hose was directed inside the furnace on the roof, quenching the fire and playing upon the slabs; which when cool were removed for examination. It was interesting to see how some materials stood much better than others. It was remarkable how the interlacing lathing embedded in the plaster seemed to give it enormous strength and cohesion. Those made of Portland cement stood very well, but not quite so well as a modification of this cement by a process which was kept secret at the time. Those particular slabs really showed no marks of injury whatever. Further experiments were carried out in a small house with brick walls, the floors and partitions being of Banks material. In one case a room was filled with pitch-pine sticks, saturated with petroleum, and set on fire. It was kept burning thirty-five minutes. The fire was so hot that the pyrometer gave way. The ceiling was formed of concrete and iron, the iron being buried in the concrete, and underneath was hung a ceiling of plaster on lathing. As soon as the period of fire was considered to be sufficient by those who were in charge of the experiment, a hose of water was played on the ceiling from within, and quenched the fire. As soon as it was cool enough, people went inside, and it was found that even ordinary lime plaster had afforded a perfectly efficient protection to the concrete floor above. The floor was indeed so cool that he went on to it before the fire was extinguished, and there saw a harvest spider walking across uninjured by the immense heat beneath. Those experiments were followed by practical building, and that system of suspending the ceilings from the columns had been adopted in almost all the hospitals that had been built during the last two or three years near London—the London Hospital, Guy's Hospital, and the great metropolitan hospitals now being erected in the suburbs—and the result appeared to be thoroughly successful. One advantage was that very great cheapness of construction was obtained as well as great facility in adding

Mr. Pye-Smith.

Mr. Pye-Smith. decorative ornament in the form of cornices and plaster-work generally.

Mr. Matheson. Mr. EWING MATHESON said it would be interesting to know how far the relative advantages of concrete as against fire-proof tiling had been considered, and whether the preference for hollow bricks was due to their superior fire-proof qualities, or their greater strength for a given load, or to the high cost at Chicago of Portland cement. It would also be interesting to Englishmen to know whether the concrete for such important foundations was made of American cement or of English Portland cement. He believed that up to the present time they had not been able to make in America, either from the want of proper material or from some other reason, a cement as trustworthy for concrete as that imported from England or Germany. The lofty obelisk in Washington, 500 feet high and of enormous weight, was found during the construction to be sinking, was under-pinned, the foundations being filled with a concrete specially made of English Portland cement. With regard to the high cost of the structures in Chicago, as mentioned by Mr. Pye-Smith, the explanation was very simple. Labour and many other things in Chicago were double the price they were in England, so that $1\frac{1}{2}d.$ here might represent 3d. there.

Mr. Golding. Mr. J. F. GOLDFING observed that reference had been made in the Paper to the provision against wind-pressure, and it was asserted that the blocking of tiles between the beams was considered preferable to concrete floors, for the reason that the structure was brace-built. The Paper showed how well they braced the building before the floor was put in. It also disclosed that in the attempt to put the floors in above the fourth floor while the building was in course of construction they had to cease putting in the block tile, because the building was swaying and they had no tie-rods in the building. A little thought would satisfy any one that the wind stress on such buildings was not much met by the insertion of tiles between the girders. On the other hand, when it was possible to put a floor into a large building and cover it with one monolithic slab, where the haunches and girders were filled with cement or concrete, a better result was obtained. With regard to veneering the exteriors of the buildings, it would be observed that it was first begun on one floor, perhaps the third or fourth, each storey being built independently on a girder, and there was a slight space left between for any settlement that might occur. At the columns they were anchored by hooks laid in while the blocks were being placed,

hooked round at the backs of the girders. To look at the construction one would think that it was very indifferent; and he would rather not be in one of those buildings in case of an earthquake. No reference had been made in the Paper to the manner in which the partitions of the buildings were constructed. The system was a popular one in America, and was becoming popular in England, of imposing a solid wall 2 inches or $1\frac{1}{2}$ inch thick; it was done by drawing rods between the girders along the line where the partition was desired, then interweaving sheets of lathing, plastering first on one side and then on the other with a quick-setting mortar, thereby constructing a wall which was quite as sound-proof as a single-brick wall. Those partitions were generally employed in America; they saved space and weight, and were very good in every way. Allusion had been made to the Athletic Club buildings in Chicago which were burnt. The building was floored with tiles; the ceiling had been plastered upon hollow tiles, and he was happy to say, not such as were used in England. He was in Chicago immediately after the fire, and the business with which he was concerned was required to work upon that ceiling. It looked comparatively uninjured, but it was cut in bays with false girders, lathing, and plaster. It was true they were intact, but the plaster had all fallen from the tiles, and some of the latter had fallen. The suspended ceiling was afterwards placed over the whole of it, where the tiling was exposed. When the workmen undertook to suspend the ceiling, many square yards of the tiling fell off. The tiles were hollow. Of course the faces were simply held by ribs extending down vertically. The action of the water had split them. A little touch caused them to fall. The men had to work at the risk of their lives. Finally the suspended ceiling was put on the whole of it, by piercing through the tiles and concrete. The effect was, the flooring strips and concrete held the remaining part of the tile in position. With regard to the question of cost, it was only recently that in concrete floors a bond of steel netting was introduced. The cost of tiled floor was 25 per cent. greater than it was a year after the introduction of concrete, with a span of 16 feet. The Stock Exchange building had floors of 16 feet clear span, according to the system that was now being introduced in England.

Mr. T. BLASHILL had been very much interested in the Paper, Mr. Blashill, which had shown how scientifically high buildings could be erected. He did not think it very likely that many such buildings

Mr. Blashill would be erected in England. Several considerations arose in his mind in connection with them. He was not at all satisfied that they could ever be made, he would not say artistically, but suitable to the construction. He was curious to know how the terra-cotta was fixed upon the iron. He should have liked to see the terra-cotta imbedded in something better than appeared from the drawings—he was not quite sure what. If he understood the construction rightly, it required that instead of following the ordinary practice, beginning with a thick wall at the bottom and gradually thinning upwards, there need not be a thicker wall in the lower storey than there was in the upper, and constructionally that was of course a great advantage. He should have thought that if the terra-cotta could have been imbedded in some such material as coke breeze concrete (which was, as far as he knew, the best fire-resisting material) it would have been much better than anything he saw in the drawings. He did not know whether there was anything in Chicago more than in other places that required the business part of the city to be only $\frac{1}{2}$ mile square. It appeared to him that they might extend the business part of the city as other cities had been extended, in a horizontal rather than in an upward direction. Tram-cars and vehicles of that kind might be used as well as elevators. The interference with light and air in the streets, and with the mutual access of light and air to neighbouring buildings, appeared to constitute a very great objection to this class of construction. He was not quite sure how a building was heated. Reference was made in the Paper to turning on the heating apparatus as if it was a necessity. He supposed that the hollow of the external wall was used as a means of conveying heat, otherwise the great cold during the winter months would strike through the thin walls, and he should think the houses would hardly be habitable. The Author did not appear to say much about the effect of an ordinary fire upon the structures. There was an interesting account of a fire which took place in a limited area. But in the case of a room well stored with combustible materials, what would be the effect if the fire actually had hold of it? Perhaps, however, there had been no experience of that kind. Again, what would be the effect of an earthquake like that recently felt in this country? It appeared to him that a building of such a kind would feel the shock from top to bottom, as there would be no elasticity about it. They appeared to have a very irregular way of going to work in America. The footways were sloped and there were steps here and there; indeed, the footway was arranged in front pretty much

as an individual liked. He did not think that could be done in Mr. Blashill, London. People would object to steps being made here and there until the house had settled into its proper position. Apart, however, from the doubts he had expressed, everyone would recognise the great ingenuity and boldness exhibited. He had been especially struck with the cantilever construction from a narrow foundation which said very much for the engineers of America, and he wished to add his humble meed of praise to the profession in America in that respect.

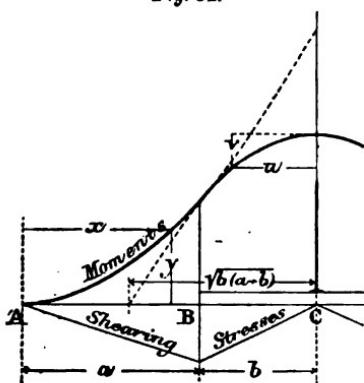
Mr. MAX AM ENDE remarked that, so far as he knew, the fire-
proof floor construction shown in Figs. 19 and 20 was, for a
required strength, the lightest which had been designed, forming
at the same time a flat ceiling. Floors made of cellular bricks
had been introduced in England more than ten years ago. In
America they seemed to date from the conflagrations in Chicago
in 1871 and in Boston in 1872. But he was not sure whether
floors substantially similar were not first made in France.¹ It
might be noted that while generally the vertical webs of the
hollow bricks had been parallel to the joists, they were here cross-
ways, which seemed to make the floors stronger. Cast-iron columns
were gradually disappearing from fireproof construction in Europe
and America. Architects who still entertained doubts as to their
disadvantages could gain very little in point of economy by using
them. He might abstain from making further remarks upon
these matters if he referred to two interesting Papers² bearing
on the present subject, and read in America not long ago. Mr.
Waite's Paper showed how deep an interest American engineers
took in the stresses of structures, as it dealt almost exclusively
with wind stresses. The permissible stresses on the metal were
even hardly referred to there, and it was of importance that the
Author of the Paper before the meeting had stated very clearly
what was the American practice in this respect. He agreed with
that practice except that he considered a stress of 25,000 lbs. per
square inch on columns under the conditions stated on p. 9 too
high, and would not allow more than 20,000 lbs., having regard to
the uncertainty still prevailing in stress calculations of this kind
—an uncertainty which must strike anyone perusing the above-

¹ Centralblatt der Bauverwaltung, 1881, p. 328.

² "The Use of Steel in Large Buildings," by C. T. Purdy (Journ. Assoc. Eng. Soc., Philadelphia, 1895, p. 182); and "Wind-Bracing in High Buildings," by G. B. Waite (Trans. Am. Soc. C.E., 1895, p. 190). See also Minutes of Proceedings Inst. C.E., vol. cxxii. p. 419; also Centralblatt der Bauverwaltung, 1887, p. 435.

Mr. Max am mentioned two Papers. It appeared to him that a correction was Ende. necessary in regard to the bending moment, as stated on p. 17, which applied to the bottom layer of girders, Fig. 23. As similar conditions obtained very frequently, not only in buildings, but also in bridge bearings, he would show the curve of bending moments for that layer, assuming that the pressures were uniformly distributed on both layers. The curve consisted of two parabolas, the apex of one being in A, *Fig. 34*, and that of the other in the centre line of the column at C.

Fig. 34.



The equations of the parabolas were—

$$y = \frac{p x^2}{2} \text{ and } v = \frac{p a}{2 b} u^2,$$

where p was the uniform pressure per lineal foot between A and C. The parabolas had a point of contact in the vertical upon B, and the parabola $v = \frac{p a}{2 b} u^2$ cut the line A C at a distance $\sqrt{b(a+b)}$ from C. The maximum moment occurred at C, and was equal to

$$y + v, \text{ when } x = a \text{ and } u = b, \text{ namely, } y + v = \frac{p a^2}{2} + \frac{p a b}{2}, \text{ whereas}$$

the moment calculated on p. 17 was only $\frac{p a^2}{2}$. The shearing stress increased uniformly from zero at A to $p a$ at B, and from that point it decreased uniformly to zero at C.

Sir Benjamin Baker. Sir BENJAMIN BAKER said as this was a Paper by an American member of the Institution, he should be sorry if the discussion conveyed an impression that the meeting had been led astray from the appreciation of the engineering features of the style of building described by any consideration of the general policy of erecting "sky scrapers"—as they were called—or discussing whether the citizens of Chicago were adopting a proper policy in spreading themselves out vertically rather than laterally. That clearly had nothing to do with the engineering aspect of the question. A Paper like Mr. Shankland's was invaluable in this country, because it reminded them of what they were apt sometimes to forget, namely, that engineers were entitled to go back to first principles when a new problem was set before them, and not to consider themselves hide-bound by precedent. The problem

set before the engineers of Chicago evidently was to accommodate Sir Benjamin a very great number of people in a given area, which meant lofty Baker. buildings on a bad foundation extending up to the surface and down (as he knew personally) to an impracticable depth. Under such conditions the engineer had reverted to a plan which was, perhaps, the earliest of all, where a soft ground had to be dealt with—that was, spreading foundations. That was a much earlier system than piling, because piling involved the use of pile-engines; whereas spreading foundations only involved the construction of a platform of trunks of trees, faggots and things of that sort, as had been found in digging up the foundations of many old Roman structures. But the surprising thing to Americans of twenty years ago would not be the spreading of foundations, but the substitution of steel for timber for such works. There was nothing new in spreading foundations in the States by great thicknesses of timber laid crossways; and, indeed, in early days a cubic yard of timber there was cheaper than a cubic yard of concrete. But now steel had been substituted, and to the American engineer of twenty years ago it would have seemed marvellous that it could pay in the United States to bury steel joists in the ground. Of course, no engineer would go away with the idea that the system would be applicable or advisable in every situation where borings showed soft ground. There were many places in England, and still more places in Ireland, where there was soil similar to that in Chicago; but often in old countries, where building had been going on for centuries, a lot of brick rubbish and other made ground was formed on the top of soft ground; and in practice it was found that the internal friction of that soil and its distributing power enabled girder construction of the kind described to be dispensed with; whereas, if the bad soil extended up to the surface without any of the made ground, it would be necessary in the absence of piling to spread the foundations by timber or concrete, or some other means. There were many places on the Continent where bad ground extended up to the surface, and the supporting power had been got by digging out trenches of moderate depth and filling in with sand, which had a similar effect to made ground. In Holland, for ages past, they had had to deal with the same ground, and they got support by driving in timber piles not to solid ground, but to a sufficient depth to enable the lateral friction on the piles, and the shearing resistance of the ground between them to distribute the load over a given area. The special circumstances of the case had therefore always to be considered. The

Sir Benjamin Baker. Sir Benjamin merit in the present case was that engineers had accepted the conditions, namely, lofty buildings and bad ground up to the surface, and had simply made the necessary calculations and adopted the results fearlessly, regardless of precedent. There was nothing abstruse about the matter. The engineer had simply gone back to first principles. With regard to the thinness of the walls, it should be remembered that in this country there were many adequately heated buildings, including the huge Crystal Palace at Sydenham, where the walls were only $\frac{1}{8}$ -inch of glass; and he saw no reason why, with those thin walls at Chicago, they should not be able to keep up the temperature which was insisted on in America, at a much less expenditure of fuel than was required in many buildings in this country, considering the large amount of glass necessary for the dark skies of England as compared with those of the States. He therefore hoped the Author would understand that English engineers did not hold him responsible for the architectural appearance of these abnormally lofty buildings or for the general policy of extending them laterally or vertically, but that as one of the members of the Institution, they congratulated him on the success with which he had adapted himself, as all engineers should, to the conditions set before him by his clients.

Mr. Walmisley. Mr. WALMISLEY said there was one point to which reference had not yet been made with regard to modern skeleton-framed structures, where vertical diagonal bracing had not been introduced—the connection of the horizontal to the vertical members. Any-one who looked at any old building, with timber floors supported by brackets attached to timber or iron vertical stanchions, would notice the great width of the bracket at the support of the horizontal members compared with that adopted in the present day. In those old warehouses, the centre of gravity at the bearing was comparatively far from the axis of the vertical compared with what it was on the connection between beam and column as shown in Figs. 2 and 3, Plate 1. That he thought was an important point to which attention might be called. It was well known that shearing stress was not properly understood in the early days of engineering, and there was also a difference in the nature of the ends of timber beams, and of iron or steel beams; but now, so long as there was sufficient bearing area and the shearing area in the connection was correct, the seating of the girder was brought as nearly as possible to the centre or axis of the column. That was forcibly illustrated in Figs. 3, and he thought it was a matter of interest to notice.

Mr. R. J. G. READ observed that a large part of the Paper had been devoted to the question of foundations, and he could not help admiring the bold way in which the Americans carried the side walls of buildings when they could not get close against a neighbouring wall. He should be glad to know the necessity for carrying the side walls on cantilevers. Was anyone in America who took a plot of ground at liberty to excavate on his neighbour's ground, and spread out foundations as wide as he chose? That appeared to be the case from the diagrams exhibited. In the case of one of the photographs shown on the screen, it appeared that the builder had to carry the side walls on cantilevers because he could not go straight down the side of his neighbour's wall. In London, when a new building had to be constructed, the ironwork had almost invariably to be connected in some way with the side walls, and it could not be carried up alone without the builder carrying up the walls with it. Again, very few English buildings were set out with the regularity that appeared to characterise the American buildings. In many of the latter there was simple repetition for twelve or fifteen storeys, and one could quite understand that in applying iron or steel construction, the engineer had a much better chance of preparing his ironwork design in a way that enabled the contractor to erect it quickly. Modern flats in London, which were the nearest approach to the buildings described in the Paper, did not exceed five or six storeys, and those were very seldom perfectly regular. The ironwork was fixed at irregular intervals. One portion of the building had to be carried by ironwork on columns or girders, while another portion was carried by walls right up from the bottom. There was therefore considerable difference in the settlement. Fortunately, however, the foundations in London were much better than those in Chicago. With regard to steel stanchions it appeared from the American Book of sections that they worked a good deal more with channels and Z-bars. He would be glad to know the comparative cost of those bars. They were very seldom seen in English lists, and if it was desired to use them in any great variety there would have to be special sections which would cost a great deal more than the plain rolled joists. He would also like to see the flooring joists shown as well as the main girders. In high buildings in London a very economical and common method was to lay upon the main joists small rolled joists about $5 \times 2\frac{1}{2}$ inches. They were spaced about 2 feet 6 inches apart, and ran up to 14 feet span, with concrete between them, making a very economical floor. There was another point worthy of consideration. It was a question of

Mr. Read. engineering to carry a large building to such an immense height on ironwork; but it was not quite the same thing as considering the treatment of ironwork from an architectural point of view. In the cases considered there was no attempt to treat the matter architecturally. As he understood it, the ironwork was completely covered; it was simply a skeleton, and therefore he did not think it would legitimately come under the head of the architectural treatment of ironwork, as would be the case in using iron where it might be freely seen as part of the construction of the building.

Sir Frederick Bramwell. Sir FREDERICK BRAMWELL said allusion had been made to the ability of Portland cement to stand heat. The ordinary brickwork of a Portland cement kiln was built with Portland cement; and he thought that was the best proof that the cement would stand heat.

Mr. Head. Mr. JEREMIAH HEAD had recently been in Chicago, and was to some extent familiar with the buildings described by the Author. He thought the Paper conveyed an impression that high buildings such as those described were peculiar to the City of Chicago and were simply the outcome of the special circumstances under which they were first devised there. But although that may have been the case in the first instance, it was no longer so, because buildings of that description were being constructed at a rapid rate, not only in Chicago, but in Buffalo, in Cleveland, in Pittsburg, in New York, and in many other large cities in the United States. They were being constructed, too, under circumstances different from those which affected Chicago—in places where the foundations were perfectly good. That seemed to show that there was some advantage found in them beyond those for which they were originally constructed. Such high buildings could not have been made or utilized at all except for two noteworthy circumstances. One was the perfecting of the manufacture of steel and its cheapness of production; the other was the invention of quick-working elevators. Clearly without those two things the buildings could never have been developed to their present condition. A great advantage had been found in the cities he had named from concentrating within a small area the offices of the principal business concerns. He scarcely thought that the members realized to what extent that had been done. In the Monadnock building in Chicago, for instance, there were fourteen floors; each floor had one hundred offices, or sets of offices, and it was computed that in the middle of the day there was in each an average of five persons, making in all 7,000 persons in the building. To be able to confer with other persons with whom business was being done without

going out of doors, and in the course of a minute or two, was Mr. Head. obviously of the greatest advantage. Then the concentration of business in a very small area, together with the development of the electric tram-car system, had enabled business men to enter a tram-car at their office doors, and at an average rate of 9 miles or 10 miles an hour, they could be taken into the suburbs. This enabled them to pick for residence the best localities, and be certain of getting there in about half an hour. In some cities the effect had been to make the value of land rise considerably in those residential quarters, and also in the business or high-building quarters, while the intermediate land had diminished in value. It was quite possible that that state of things would not suit people in England, and especially in London. That might be so, but he thought it was premature to come to any decision on the subject at present. The advantage of concentrating business in high buildings was now universally recognized in the United States. It was not yet fully appreciated here, nor could it be appreciated without going to see what was actually being done in other countries. With regard to the steel framework on which so much depended, the great bulk of it had hitherto been made by the Carnegie Company, and it had so far been made by the Bessemer acid process. In the summer of 1895, that Company were selling the joists and channels, whatever section was required, at 27 dollars per ton at the works. For an additional 5 dollars, 32 dollars in all, they were cutting to length and putting in all the holes and doing all the fitting required, so as to hand them over to the contractor ready for erection. The cost came to about £6 13s. 4d. per ton, delivered in trucks at the works. That would give an idea of how very cheaply the work was being done. There was, however, at present a tendency for architects and engineers to specify open-hearth steel instead of Bessemer steel for the work, and there was also a tendency to make all open-hearth steel in basic instead of in acid-lined furnaces. Some remarks had been made as to the impossibility of making very high buildings look beautiful. As to beauty or ugliness, that was a question which could not well be argued, because it depended so much on what one was accustomed to, but he thought that no one could look at the high buildings in New York without admiring them as engineering structures, and also the artistic effect that had been produced both on the exterior and in the interior. The central hall and the passages were heated by the proprietors of the buildings, either by steam or hot water. There was no need to be afraid of cold within doors in the United States, although their

Mr. Head. winters were much colder than those in England. Americans were fond of heat, and one seldom went into any buildings in winter time without finding the temperature at 70° to 80° F.—in fact, it was as a rule too hot for an Englishman. Individual offices were generally warmed by a radiator—a grid-iron apparatus with steam inside. With regard to street pavements, no doubt they were sometimes very rough, especially if there was any subsidence near new buildings. It should be remembered that in New York, all which was built on a tongue of land with a large river on each side, land was exceedingly valuable. In the neighbourhood of Wall Street, land had been sold at three times the price realized in the dearest parts of London. That was because of the exceedingly limited quantity of the land there suitable for business purposes, and those were the places where one might expect to find high buildings, so as to utilize it to the utmost extent.

Mr. Shankland. Mr. SHANKLAND, in reply, desired to express his appreciation of the kindness manifested in the discussion. The difficulty of treating the whole subject of Skeleton Construction within the limits of one Paper would account in part for his communication being disconnected and, at times, vague; but that fact only emphasized the courtesy and appreciation shown in the remarks. Sir Benjamin Baker's very kind remarks had answered so fully most of the points raised that there was very little left to reply to. In answer to the President: The terra-cotta was laid in cement mortar and was in all cases backed with brick masonry, and the hollow faces of the terra-cotta were also filled with brick and mortar. The brick backing was anchored to the steel frame either by hooking rods over the frame or by passing them through holes punched in the frame for that purpose. Each piece of terra-cotta was anchored to the brick backing and also to the steel frame whenever possible. The anchors used were either copper, galvanized iron, or black iron dipped in asphalt. Regarding the power of Portland cement concrete to stand fire and water, Mr. T. T. Johnston, Assistant Chief Engineer of the Sanitary District of Chicago, had just published a record of a series of tests made by him on cement briquettes.¹ Briefly, they consisted in first drying the briquettes for a week or more, in order to drive out all the uncombined water, then roasting them in a pan without directly exposing them to the fire for four and a half hours to six and a half hours, allowing them to cool slowly, and then breaking

¹ *Engineering Record*, December 19th, 1896.

them. These briquettes were four and a half months to twelve Mr. Shankland months old, and all showed a loss of strength due to the heating, the loss ranging from 58 per cent. to 89 per cent.

In reply to Mr. Max am Ende, the fibre stress in the columns never exceeded 15,000 lbs. per square inch for live and dead load, and was further reduced for long columns. It was improbable that the 25,000 lbs. fibre stress spoken of as resulting from the combined live and dead loads, and a wind-pressure of 30 lbs. per square foot, ever obtained in a column; if so, it occurred only at long intervals and was of momentary duration. As stated in the Paper, this was not more than in the best bridge practice, which allowed the combined stress from live, dead and wind loads to be as high as 25,000 lbs. per square inch. That amount was allowed as a maximum in a heavy railway bridge of 525 feet span built a few years ago.

Correspondence.

Mr. S. G. ARTINGSTALL observed that Chicago lay on the edge of Mr. Arting-
an ancient lake, of which Lake Michigan was the existing stall.
evidence. The lake had as an outlet a river draining towards the Gulf of Mexico by way of the Desplaines Valley, the Illinois Valley, and the Mississippi River. Chicago was situated over the bed of that ancient river, and the character of the deposits upon which the city was built and upon which the buildings were erected was uncertain and unreliable. The business part of the city was on the southern part of the main channel of the ancient river, the depth to the rock being 80 feet to 100 feet below city datum, or 94 feet to 114 feet below the level of the streets. This rock was overlaid with a cemented gravel or hard pan, over which was clay, tolerably firm at first, but quickly changing to a soft clay of about the consistency of soft putty. Above the sewers, or about the level of the water in the lake or river, the ground water had been drained off and had left a firm soil or deposit, upon which ordinary buildings could be erected with security.

When heavy structures had to be erected, the engineers had found out by experience that ordinary formulas could not be depended on, but that the area of the foundations under each wall, pier, or column must be carefully proportioned to support its part of the load, or unequal settlement would result. That had been shown by numbers of buildings, as for instance, the Board of Trade. The tower, about 300 feet high, had been taken down

Mr. Artingstall because of its badly proportioned foundations. The Dearborn Station tower had been cut away from the main building twice, so as to allow it to settle and not wreck the building. In the City Hall, the floors in a span of 40 feet were 18 inches to 24 inches out of level before the building was completed, and the floors and ceilings are furred to that extent to make them level. Many instances could be given where foundations were built in the usual ordinary manner, and disaster to the structures followed, but by experience the foundations of all important buildings received great attention and careful design.

In constructing the tunnel under the river at Harrison Street, the ground (clay) was so soft, and the use of compressed air not being available, that all the miners put in the face could not remove it as fast as it flowed in. Again, in dredging the river and harbour, of which Mr. Artingstall had charge for more than twenty years, when a channel of 18 feet to 20 feet in depth was made, it was found that one or two years afterwards it was but 14 feet to 16 feet deep. The next dredging showed very little deposit on the surface, but always virgin clay, indicating clearly that the natural strata of material which underlay the central or business part of the city was of very soft or semi-fluid material.

Mr. Howe. Mr. HENRY M. HOWE confessed some apprehension as to the resistance of the steel structures to corrosion and fire. As the strength of a chain was measured by its weakest link, so the strength of any part of a steel skeleton structure was that of the most rapidly corroding member below it; and its safety in regard to fire was that of its member most exposed to the heat, in the sense that the failure of a lower member, whether from corrosion or collapsing, might bring down the whole structure above it. The rate of corrosion varied so very greatly with the conditions, that any formula, like that quoted in the Paper, should be used only with great caution. The amount of salt, of moisture, of sulphurous acid, and perhaps of ozone in the air, the temperature, the wind, the thoroughness of protection by paint, &c., all affected the corrosion greatly. It appeared to him yet to be shown that those in charge of the tall steel structures would, or could, invariably exercise such supervision and so protect the metal from corrosion as to guarantee its safety. It would be difficult to exaggerate the care that should be taken to protect from corrosion all the steel parts, especially those which must be inaccessible for inspection, for renewal of protective coating, and for replacement. While fires within common office buildings were unlikely to heat the steel skeleton so much as to cause it to buckle, yet fires

from without might well do so. A steel skeleton building might easily be menaced by the neighbourhood of inflammable buildings. Mr. Howe could readily understand that, if but a moderate thickness of brickwork or stone were between the steel skeleton and the outer face, the burning of neighbouring buildings might readily heat that skeleton to such a degree as to cause collapse. As that would be most likely to occur in the lower storeys, its consequences would be terrible. It might be well that the steel skeleton of the outer walls either should begin far above the ground-level, or should be protected against fire by an ample thickness of brick or of stone. Against earthquakes the steel skeleton construction should give much greater security than masonry of equal height.

Mr. W. L. B. JENNEY mentioned that in the autumn of 1892 he was appointed architect for a tall fireproof building, which the Home Insurance Company of New York proposed to erect in Chicago. The instructions were that all storeys above the bank-floor should be divided into the maximum number of small offices, all well lighted. As was foreseen, this arrangement reduced the piers between the windows, so that the ordinary masonry construction would not carry the load in lower storeys. To thicken the piers into the building was objectionable. The natural solution was to build an iron column in each pier to carry the floors. The question of expansion and contraction of continuous columns 150 feet high subjected to a variation of some 120° F. then presented itself. This suggested carrying the walls as well as the floors, storey by storey, on the columns, thus dividing the movement. The details followed naturally. That system of construction resulted in another very decided advantage when building on a compressible soil, such as underlay the business district of Chicago. The outside walls, being only self-sustaining and of the height of a single storey, could be reduced to the thickness necessary to fireproof the steel, to hold the window-frames and to produce the desired architectural effect, greatly reducing the load on the foundations.

It was the result of experience that the clay underlying Chicago under a given load not exceeding, say, 4,000 lbs. per square foot compressed to a certain point, soon stopped and was not further compressed without a material addition to the load. After the clay had been compressed for a considerable period certain additions could be made to the load without further settlement. The settlement increased rapidly as the load increased, after passing the 3,500 lbs. limit. Mr. Jenney's experience had been that if the maximum load on the clay did not exceed 3,500 lbs. per square

Mr. Jenney. foot for buildings not exceeding 160 feet in height (unless of very large ground area) the settlement would not exceed 4 inches. As an illustration of the principle that light loads would only produce small settlements, the Fair, a store building, Dearborn and State Streets, Chicago, was calculated for sixteen storeys. Only nine were built. The levels taken four years after showed a maximum settlement of only $1\frac{3}{8}$ inch. As stated by the Author, the practice had been not to cut into hard pan. This so-called hard pan differed from the clay for many feet below only in containing less water. The value of the hard pan was that it added something to the shearing on the outline of the foundations as they settled into the clay. Certainly this was not very important. In the Young Men's Christian Association building, commenced 1892, the necessity for a high basement to accommodate a swimming tank, boilers, etc., forced Mr. Jenney to cut some 2 feet into the hard pan. The actual load on the clay was 3,500 lbs. per square foot. The maximum settlement from levels taken 10th January, 1894, was $2\frac{1}{8}$ inches. The building was erected much more slowly than any other of the Chicago tall buildings, two years from commencement to finish, instead of about ten months, which no doubt reduced the total settlement. It was well known that in driving piles into Chicago clay, quickly repeated blows were the most efficient, and that if a pile was partly driven and then left, say, one night, materially more force was required to start it again than if the driving had been continuous.

The calculation of the foundation beams has been a matter of considerable discussion among American engineers. The method described by the Author was extensively used, and practical results seem to justify it. Another method, which was used by Mr. Jenney, was to consider each layer of beams separately, and find the moment at the centre; the concrete was not considered as subjected to horizontal stresses. By this method more steel was required, which was not objectionable, as the steel in the footings might be subjected to conditions likely to produce corrosion. For this reason it was his practice to have the foundation beams, as well as all other steel in the building, oiled at the mill and painted at the building. As all assembling was done with hot rivets most of the painting had to be done after erection.

There had been a sufficient number of opportunities to obtain the relative cost of the two systems of construction to establish the fact that the steel skeleton was the least expensive. The steel skeleton had been in use some thirteen years, and had been subjected to all the usual conditions. It had been shown by tests

made during a severe gale that it was even more rigid than heavy masonry buildings. A cyclone might blow in the windows, but the frame being a network of steel, braced in every direction and securely riveted together, would sustain less damage than other systems of construction; so that it might be truly said of these buildings that they were wind-proof, fire-proof, and earthquake-proof.

Mr. G. S. MORISON remarked that the Paper described a new system of construction which was remarkable for its rapid development. The rapid development of any novel construction was sure to be accompanied by defects whose importance was not at first realized; and he considered that the system of skeleton construction was no exception to the rule. Iron bridge building in America might be given as an instance. The earliest bridges, generally designed by careful engineers, were followed by a class of structures built by designers who studied simplicity and economy of construction. Those structures fulfilled the requirements for vertical loads, were economical in material and were erected with extraordinary rapidity; but they were loosely put together and were adapted so closely to existing rolling-stock that they were quickly superseded. Constructed by contract from contractors' designs, they were still used largely for highway work; but on railways they had generally been superseded by carefully designed structures, in which something more than the weight to be carried was considered, and which were equal in rigidity and massiveness to the structures built in Europe. Steel skeleton construction was in its earlier stage. The novelty came with the first design; the economy was at once apparent; buildings in which everything was reduced to a minimum of material represented the present state of the art. This construction was now being used largely in New York; but as the natural foundations were much better there than in Chicago, and the general demand was for better structures, although some exceedingly bad work had been done in New York, the better class of buildings were better built there than in Chicago. The buildings in the latter city were adequate to carry the weights which were likely to be imposed upon them, though the stresses and weights given in the Paper showed that the factor of safety was not large; while the formula used for the strength of long columns was one not properly applicable to any but comparatively short columns. Settlement occurred in the foundations, and that had produced, even in some of the later buildings, deformations which though perhaps not serious were at least displeasing. Vibrations from machinery or passing heavy

Mr. Morison. loads were distinctly felt in the highest storeys. The provision to resist wind-pressure was often imperfect.

The general method of spreading foundations over a considerable area of soft material was not new, though it had seldom been found absolutely satisfactory; it was, however, cheap and quickly done. In structures of irregular shape, in which very different weights were carried by different columns, it did not give good results. If the areas of the footings were proportioned according to the weight carried, uniform pressures were given at the bottom of the footings only; but the compression of the soft material extended indefinitely below those footings, and the pressure ceased to be uniform lower down. For that reason, light columns with small footings generally settled less than the heavy columns. That system of foundation could be made really satisfactory only for structures of regular, uniform shape, in which the weights of the several columns were kept uniform, so that footings of equal size were used. The general principle of all those designs was to provide a metallic skeleton to carry the weight. That was perfectly simple. The weight of each separate storey, including the outer walls, would be transferred directly to the skeleton frame, and the modulus of elasticity of ordinary masonry was so small in proportion to that of iron or steel that it readily accommodated itself to any compression caused by weight. The same might be said of temperature. The expansion of masonry and steel was so nearly equal, that when they were kept at the same temperature no disturbance need be expected from that source, and the enclosure of the steel skeleton in some form of masonry accomplished that result. When, however, other elements were introduced, the conditions were different. The rigidity of such a structure was elastic, and not the rigidity of mass. A tall, narrow building was subjected by wind to a horizontal pressure which it could only resist as a vertical beam. If such a beam had strength to resist the maximum wind-pressure, the building as a whole was safe. If the bending was insufficient to crack the masonry, the building was all right. As no one knew the maximum possible wind-pressure, it was wise to utilize that form of construction which would give the least deflection with permissible stresses, and that was the one in which the members relied upon to resist bending had the greatest horizontal dimensions.

The Paper described three methods of resisting wind-pressure. The first was by a series of diagonal rods, which really formed a system of trusses whose depth was the width of the building.

That, with proper details, was the best method of the three; but Mr. Morison, the Author had discarded it for no better reason than that it might interfere with partitions. The second method was by the use of portals connecting the vertical posts—a good arrangement if carefully worked out, though it necessarily threw some bending stresses on the posts; but that was rejected because of its cost. The knee-braces mentioned in the Paper were only a modified form of portal bracing. The third method relied entirely upon the stiffness of the posts and their connections to resist lateral flexure, thus reducing the width of the beam from that of the whole building to that of a single column. Such reduction was, however, less important than might at first sight appear, because the length of each separate member was reduced to that of a single storey. It had been adopted generally because of its convenience in construction. It was safe if carefully carried out; but it greatly increased the stresses to be resisted by the posts and made the design of the posts of special importance.

There was another method of resisting wind-pressure, to which the Author made no reference; but which, in Mr. Morison's opinion, was better than any of those named in the Paper. It was used in most of the earlier buildings. It consisted of making the outside walls of the building composite beams, in which the vertical posts formed the chords, or booms, of the trusses, and the floor-beams combined with the brick walls formed the webs. A building of that kind enclosed by four walls, with proper details for metallic connections and for the support of the filling, and with windows and openings carefully placed, was a very satisfactory structure. It was really a box composed of four deep vertical beams, stiffened by as many horizontal beams as there were floors. He considered that when the subject had been fully investigated that would be the only form of skeleton structure permitted. The outside walls, with such help as they might get from partitions, were the main-stay of some of the buildings. While a building with four walls was decidedly the best form, a satisfactory structure might be made with only two walls provided those two formed adjacent and not opposite sides. If, however, the "table-leg" principle, which relied only on the strength and stiffness of the columns to resist wind-pressure, was used, it was of the utmost importance that the connections between the floors and the posts should be as rigid as possible, and that the posts should be properly designed to act as vertical beams.

The designs described in the Paper did not meet these require-
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Mr. Morison. ments, and strength and durability were sacrificed for speed and convenience of erection. The floor system should be carefully riveted to the posts, so that there would be no lost motion; but the specifications provided for bolts instead of rivets, and instead of being turned with a driving fit in reamed holes, these bolts were $\frac{1}{2}$ inch smaller than the holes. The objection advanced by the Author to box and Z-bar columns was that he thought them laterally weak, whereas both of those forms of column had continuous webs, and their strength and rigidity could be determined absolutely by well-known principles. It was only necessary to increase their dimensions until the necessary rigidity was obtained. The column, known in the market as the "Gray" column, which undoubtedly possessed great advantages in regard to rapid erection, was unfit to resist transverse strains, and the only tests which had been published indicated that it was rather weak when considered only as a post. This column was formed of eight angle-bars, which, in the lower storey of the Fisher building, appeared to be connected by three sets of tie-plates of thin metal 8 inches wide; such a column was really without a web. When subjected to bending-stress, it was not a single post but a bundle of eight faggots. Within small limits it might be safe; but its stiffness could only be secured by extreme local strain in the angles and extreme bearing strain in the outside rivets of the tie-plates. If continuous plates were substituted for the tie-plates so as to provide a web, that column might be an excellent one. As constructed, it was without either a radius of gyration or a moment of inertia, though the latter element had apparently been determined on the supposition that the tie-plates were equivalent to a web. In the Fisher building, which was referred to in the Paper as the highest development of this class of construction, the entire wind-stresses were resisted by those webless columns. Apparently, the strength of the columns as beams had been calculated on the basis referred to. The building stood without brick walls on any side, having only a covering of thin hollow terra-cotta blocks on the north side, the other three sides consisting of bay windows. The continued existence of the building would confirm the view held by many engineers, that a wind-pressure as high as 10 lbs. per square foot over the entire surface of a large building was of extremely rare occurrence.

Mr. Robson. Mr. J. J. ROBSON inquired the thickness of the cement and six-ply tar and gravel on the roofs. The gas- and water-pipes appeared to be conveniently hidden in hollow spaces in the columns; how were they rendered accessible in case of accident or renewals?

What description of tiles was used for the fireproofing surrounding Mr. Robson's columns? He considered the pile foundation bad in principle; the piles seemed to be unevenly loaded, and the outside piles would really bear a greater weight than those inside. The cantilever projection of 6 feet could have been reduced by one or two additional rows of piles, even if those close to the footings of the adjacent buildings had to be screwed instead of being driven. The cost given averaged about 1s. 10d. per cubic foot, which was twice the price of large hotels and blocks of flats recently erected in London (which averaged between 10d. and 1s. per cubic foot). His experience of ordinary building work in America was that it cost about the same as good work in England, but any special or artistic work cost very much more. An allowance for a wind-pressure of 30 lbs. per square foot appeared to be sufficient for America, but would not be safe in England. That allowance of American engineers confirmed his opinion that the wind velocities of America were not so great as those which were sometimes experienced on the coasts of Great Britain. The highest wind-velocities obtained in England were those recorded at Fleetwood on the Lancashire coast, where the Meteorological Office had a station. There gales frequently attained a velocity of 80 miles or 90 miles per hour, whilst during the great gale of 22nd December, 1894, the average for the twenty-four hours was 96 miles per hour (= 27.65 lbs. per square foot); the highest average over one hour was 107 miles (= 34.35 lbs. per square foot); whilst the highest average during twenty-three minutes was 123½ miles per hour (= 45.75 lbs. per square foot). He believed that in England it was necessary to allow for a minimum pressure of 50 lbs. per square foot, for in addition to the results mentioned from Fleetwood (which were averages), there were the momentary gusts which it was impossible to record.

Mr. CHARLES L. STROBEL pointed out that the most important Mr. Strobel's consideration in designing the steel skeleton for a tall building was the proportioning of the parts and their connections so as to afford sufficient resistance to wind-pressure. Some resistance would be afforded by the partition walls and the outside veneering of terra-cotta in buildings of the description referred to; but those parts were usually made so thin and light that the steel frame of the building was called on to furnish nearly all the resistance to wind. Further, for convenience during construction, all the storeys above the second or third floors, including the roof, were frequently completed while the first or the first and second storeys were still without outside walls or partitions, so that, as

Mr. Strobel. long as that condition lasted, the ironwork was called on to resist all the wind-stresses.

The most efficient and economical wind-bracing was a system of diagonal rods in vertical planes, making a braced tower of certain parts of the building; but that type of wind-bracing was frequently inadmissible on account of its interference with doors and windows. The portal bracing referred to by the Author had been used for very high buildings with small bases, and for such cases, if diagonal rods were not admissible, would seem to afford the most satisfactory solution of the problem. That plan not only provided for the considerable number of rivets necessary for the connection of girders to columns to resist the bending moments, which were very large in such cases, but the column itself was greatly strengthened for resisting transverse stress. For those conditions, the column shown in Fig. 3, Plate 1, consisting of eight angle-bars, connected by bent batten plates, would be inadequate, as not possessing sufficient bending strength, and for other reasons. That column had only the transverse strength of the eight angle-bars composing it, acting independently and not as a unit. Further, in the case of heavy columns, the number of rivets connecting one segment with another would be entirely inadequate to resist such shear as was likely to occur; and there was not sufficient strength locally, where the girder was connected with the column, to resist the couple acting at that point. The effect of the large horizontal forces acting at that point would be to press the two angle-bars of the column in at the lower flange of the girder, and to pull the two angle-bars at the upper flange of the girder out, or *vice versa*, the batten plates resisting this action only by their resistance to bending, which was slight. For all cases requiring that the columns should furnish considerable resistance to bending, they should be made of continuous metal closely riveted.

The Author had not done full justice to the advantages of the use of joint-plates. The main reason for their use had been to assure good bearing between the abutting surfaces of two-column sections, and to provide for carrying several beams alongside of one another, as was frequently desirable where a massive treatment of the walls was desired. For those reasons joint-plates were used, for instance, in the Century Building, St. Louis, at present approaching completion, where Georgia marble was used for the outside walls instead of terra-cotta, and the corner, and some other piers were built of solid masonry. The joint-plate admitted of an excellent connection between beam or girder and column for resisting wind-stress, as the rivets were strained in shear and acted

at a maximum leverage. In the case of direct connection of Mr. Strobel's girders with columns by angle-bars riveted to the web of the girder there was tension against the rivet-heads, and the rivets acted with an unequal and smaller leverage. The joint-plate should reach out so as to take hold of four or more rivets at the bottom of the beam or girder. The upper connection of the beam or girder was less convenient, but could be made entirely satisfactory. Usually angle-bar connections were used. One half of those connections would be strained in tension, so that a pull would be exerted upon the rivet-heads. The other half, however, were strained in compression; for those the girder could, in addition, be made to abut directly against the column by inserting iron wedges.

Generally, it was not convenient to rely upon the interior columns furnishing the full resistance of their strength to wind-pressure. The connection between beam and column was then made of such strength as was convenient, so that a part only, say one-fourth, of the total wind-pressure was resisted by the interior columns. The remainder of the total wind-pressure was then resisted in the planes of the outside columns, either by a bracket-connection between the wall girders and the columns, or by making the girders sufficiently deep, so that by riveting direct to the column without brackets sufficient strength of connection was obtained.

Mr. Strobel considered it inadvisable to impose as high a stress as 15,000 lbs. per square inch for vertical loads upon columns, and 25,000 lbs. per square inch for combined vertical loads and wind-pressure. He had adopted 12,000 lbs. per square inch and 18,000 lbs. per square inch respectively as the limits, and in the early period of the construction of high buildings those limits were generally adhered to. It was true that stresses of 16,000 lbs. per square inch were customary for beams and girders in buildings, but those parts were not as likely to be overstrained from causes which could not be controlled as columns were, and the failure of a beam in a building was a much less serious matter than the failure of a column. The following considerations caused him to think that more moderate stresses should be used for columns in buildings. The settlement of buildings was rarely entirely uniform, and especially was that true for the conditions which prevailed in Chicago. Inequality in settlement would throw additional loads upon certain columns, relieving others, and might also cause distortions which would considerably modify the stresses obtained by calculation. Those inequalities of settlement in the case of one tall building in Chicago had caused it to be as much as 6 inches out of the perpendicular. Comparison had been made with the stresses

Mr. Strobel. customary for bridge work; the causes referred to, and which resulted in large secondary stresses, did not, however, exist in bridge work; and further, the care and thoroughness with which the latter class of construction was carried out was not usually possible in building work. One reason for this was that building work in America was usually hastily executed. Then again, it was difficult to get at some of the parts to perform the riveting efficiently, so much so, that bolts were frequently substituted for rivets in those connections, either in whole or in part, whereas allowance for the weakening effect of bolt-holes in columns was not ordinarily made in the calculations.

In conclusion, it should be stated that, so far, experience with completed buildings of the description considered would seem to indicate that a wind-pressure of 30 lbs. per square foot over the entire surface of a building was never even approximately realized in a compactly-built city, excepting, perhaps, in the case of tornadoes of the most unusual and violent kind, such as destroyed a part of the city of St. Louis in 1895. Tempests of that description would destroy all the glass windows in a building, and probably the terra-cotta veneering would be blown off as well, and the question of course arose whether a building should be designed to withstand forces of such unusual kind, which, for most localities, might be likened in the rarity of their occurrence to those arising from earthquakes.

Mr. Wilson. Mr. JOSEPH M. WILSON remarked that the method of steel skeleton construction had been a natural growth from the substitution of iron and steel for wood, and the demand for higher buildings which the new material rendered it possible to build. The original framed wooden building was essentially a skeleton construction covered outside with wooden boards. Then came the suggestion of a less inflammable material for this covering, and as long ago as 1873 he had suggested for temporary buildings of the Centennial Exhibition thin walls of brick as an outside covering, stiffened inside with timber framing, by which the roof was also to be carried. Residences were built in that way in many of the States, and he saw, several years ago, one under construction at Milwaukee with a skeleton of timber framing and a 4-inch facing of brick built outside anchored to the timber at frequent intervals, making in many respects a very good and serviceable building. In 1880-81 he had used, in the construction of the Broad Street Station, Philadelphia, wrought-iron columns from the ground floor upwards, encased in masonry carrying a second floor, then extending to the third floor and carrying plate-girders, on which was built the upper part of

the rear exterior wall of the building. The structure was sub- Mr. Wilson. divided into a series of parallelopipeds, wrought- and cast-iron columns being placed at the intersections on a similar system to that now adopted for skeleton buildings; and the interior walls and floors were carried on girders between the columns, the building being a type of the more perfect skeleton structures which came afterwards. In 1887, the Drexel building in Philadelphia was designed by Mr. Wilson's firm, and was built on a system of skeleton construction, columns being placed in the exterior walls, which carried their own weight for the full height, but were stiffened laterally by the encased columns which also carried the ends of the floor girders. The skeleton construction sustained the floors and division walls independently in each storey, thus allowing any arrangement of rooms and fireproof partitions, without reference to their disposition in the other storeys. Philadelphia was fortunate in having, as a rule, good foundations, generally of gravel, and the load placed on such foundations was usually between 6,000 lbs. and 8,000 lbs. per square foot. Some foundations, as those of the City Hall, were carried down to water-gravel, which consisted of a mixture of gravel and clay, in what might be called the first stage of rock-formation. He had seen a case where the load on that material was 12 tons per square foot, but some settlement had taken place in it.

Referring to the Author's practice in regard to wind-pressure, the maximum stress for live, dead, and wind-stresses, while allowable in Mr. Wilson's opinion for buildings, was beyond what he would use in bridges. In his practice he made it for bridges from 15,000 lbs. to 17,000 lbs. per square inch in tension members, and not more than 15,000 lbs. per square inch in compression members, with a reduction, of course, for length. He quite agreed with the Author as to the preservative properties of Portland cement, but it should be free from lime, otherwise it might expand and crack the steel when in a confined place, as had occurred in his experience.

Mr. SHANKLAND, in reply to the Correspondence, agreed that the Mr. Shankland method of calculation referred to by Mr. Jenney was theoretically correct for parallel tiers of beams piled loose; but the beams as actually placed in the foundations, or in layers at right-angles to one another, and embedded in a solid mass of concrete, made the whole foundation homogeneous, like a masonry wall. The following formula¹ had been given by Prof. Malverd A. Howe, for

¹ "Retaining Walls for Earth," Third Edition, 1896, p. 80.

Mr. Shankland. the safe projection for iron or steel beams embedded in concrete:— Let I denote the moment of inertia of the section; h , the depth of the beam; p_e , the intensity of the pressure upon the bed of the foundation transmitted to the beam; R , the modulus of rupture of the material composing the beam; and F , a factor of safety.

Then

$$p_e \frac{O^2}{2} = 2 \frac{R I}{F h}$$

or

$$O = 2 \sqrt{\frac{R I}{F p_e h}} I$$

Taking the foundation mentioned at p. 17, more beams would be required by the formula of Mr. Jenney, and less by Prof. Howe's formula, than were actually used, the latter number being about the mean of the two. The Table of safe projections for steel beams given in the "Pocket Companion" of the Carnegie Steel Company agreed with Professor Howe's formula. The formula for corrosion was only cited as a curiosity. The outside columns were, as stated, filled with concrete to resist corrosion and fire. It had been truly remarked by Mr. Howe that the greatest danger of fire came from adjoining buildings, and not from within. Every piece of the steel frame was carefully covered with fireproofing material, and when that was done and the outside columns were enclosed with brickwork and filled with concrete, it seemed that all possible precautions had been taken to protect the building both from fire and from corrosion. In reference to Mr. Morison's remarks, it must be observed that, in designing foundations for piers, proportioned to the load they had to carry, variations were always made in the weight allowed per square foot, depending upon the relative position of a footing in the whole system; because the upholding quality of the earth under an inside footing, for instance, was not the same as that under an outside pier. The practice was to lay out a footing under each pier exactly proportioned to the weight to be carried, and to increase, on the proper sides, footings, the earth under which should not be subjected to the same lateral pressure as that under others, and the effect of the pressure of the prevailing winds on foundations was always taken into consideration.

He had made no reference in the Paper to "the best system of wind-bracing," alluded to by Mr. Morison, for the reason that the outside walls of steel skeleton buildings were made precisely in the manner described. He believed that the steel frames of the first two tall buildings having vertical trusses for wind-bracing

were designed by himself. That was when the art was newer and Mr. Shankland, when he had less experience than now. The system of diagonal rods in a vertical plane was direct and secure; but there were other methods of meeting wind-pressure as simple and as sure, which did not defeat the object for which tall buildings were erected, viz., the use of floor space for suites of rooms. It would be as reasonable to say that the foundations of all buildings should reach the living rock, as to assert that the only wind-bracing permissible in tall buildings should be diagonal rods in a vertical plane. No scientific tests had ever been made, as far as he knew, to determine the transverse rigidity of the different kinds of columns in common use, but all the practical tests in the shop and in erection proved the Gray column to be much stiffer transversely than the Z-bar or the box column with two sides latticed. With regard to the assertion that "the entire wind-stresses were resisted by webless columns in the Fisher building," the truth was that the building was filled from top to bottom with partitions parallel to the sides, made of very stiff fire-clay tile, 4 inches and 6 inches thick, often only 8 feet apart, the whole forming a bracing that would probably withstand the highest winds. As stated in the Paper, when designing the columns, he had provided for resistance to a wind-pressure of 30 lbs. per square foot over the broadest side of the building from the foundation to the cornice. The highest wind observed in Chicago had a velocity of 115 miles per hour, and its greatest velocity maintained beyond a few seconds was 84 miles per hour, corresponding with a pressure of 35 lbs. per square foot. But the supposition that even an 84-mile breeze would not cause a greater pressure than 10 lbs. per square foot over any face of the Fisher building was probably correct. With regard to the bay-windows, the building on one side had eight panels between steel exterior columns from top to bottom. Four of them were filled with bay-windows for part of the height, and the structure of those was designed to, and did, stiffen the building materially. Two of the other sides had bay-windows, one being like that described, and the other having five panels, two of which were filled with bays for part of the height.

The exterior covering of the steel columns was not a thin shell, but consisted of first, an air space; second, hard-burned hollow tile, 3 inches thick, each piece being fastened to the column with heavy copper wire; and third, the exterior face of very heavy terra-cotta, burned almost to vitrification. This vitrified terra-cotta was between 6 inches and 12 inches thick, and formed the best fire-proofing for steel structures yet devised.

12 January, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President,
in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Member.

WILLIAM ARNOT.	JOHN MUTHVEN.
THOMAS BURRELL BEWICK.	JAMES MORE, Jun.
GEORGE PROCTER CARLESS.	EDMUND OLANDER.
HENRY SLADE CHILDE.	JAMES NOAH PAXMAN.
GEORGE FARREN.	FRANK EDWARD PRIEST.
ROBERT MACNISH GALE.	EDWARD SANDEMAN.
HENRY HERBERT HELLINS.	JOHN SMITH.
JOHN ELLIS HUGHES.	WILLIAM WILLOX, M.A. (<i>Aberd.</i>)
	GEORGE WILSON.

And that the following Candidates had been admitted as

Students.

CHARLES DICKSON BELL, B.Sc. (<i>Victoria.</i>)	WILLIAM RICHARD MACDONALD.
ARNOLD ELLIOTT.	ARTHUR WILLIAM MENZIES.
ALASTAIR MACPHERSON GRANT.	RICHARD FRANCIS MORRIS.
FRANCIS STEWART HARVEY.	TOM OSBERN MULLINGS.
CHARLES HERBERT HEATON.	DEANE HERVEY SLACK.
JOHN WILLIAM HIPWOOD.	FREDERICK SLAUGHTER.
EDWARD WILLIAM HOLLINGWORTH, B.A. (<i>Cantab.</i>)	WILLIAM FREDERICK SMITH.
	JOHN REGINALD TAYLOR.
	ALFRED JOHN PARKER THORNE.
	GILBERT WATERHOUSE.

The Candidates balloted for and duly elected were: as

Members.

MICHAEL RATCLIFFE BARNETT.	JAMES ROSSITER HOYLE.
ERNESTO ANTONIO LASSANCE CUNHA.	CHRISTOPHER CLARKE HUTCHINSON.
JOSEPH GARLAND.	EDWIN LEWIS MARTIN.
WILLIAM WYLIE GRIERSON.	HUGH REID.
	SIDNEY BEAUFOY WINSER.

Associate Members.

FREDERICK THEODOR AMAN.	WALTER WILLIAM MURRAY KITTO.
ANDREW WALKER BELL.	CLAUD HOPE KNIGHT.
JOHN CHRISTOPHER BLUNDELL.	RENZI WALTON MACFARLANE, Stud.
BRANDON TALFOURD BRIERLEY.	Inst. C.E.
CHARLES THEODORE LYTTELTON BRISTOW, Stud. Inst. C.E.	JAMES EDWARD McNELLAN.
MICHAEL JAMES BUCKLEY.	WALTER LEAHY MANSERGH, Stud. Inst. C.E.
GEORGE MUIRHEAD CLARK, B.A. <i>(Cantab.)</i>	EDWARD HUGH DYNELEY NICOLLS, Stud. Inst. C.E.
BENJAMIN CONNER.	GEORGE JOHN PRICE, B.A. (<i>Dublin</i>), Stud. Inst. C.E.
MARTIN DE VILLE, Stud. Inst. C.E.	HENRY WEDGWOOD RENDEL.
FREDERICK JONATHAN DOWN.	HARRY ALFRED RICHARDSON.
HERBERT ELLIS DUNCAN, Stud. Inst. C.E.	CLARENCE OLIVER RIDLEY.
FRANCIS OVER EVERARD.	FREDERICK MURRAY ROYLE.
ADAM MAITLAND FAIRBAIRN.	FREDERICK ROBERT RYMAN.
HENRY BLIGH FORDE.	EDMUND SMITH.
RICHARD GOODMAN.	THOMAS SMITH, B.E. (<i>Dubl.</i>)
ROBERT THOMAS HAYES.	JOSEPH CHARLES SYKES, Stud. Inst. C.E.
AERTHUR HINDLE.	HARRY WILLIAM TAYLOR.
ALBERT HARRIS HOWARD.	FREDERICK JAMES WOOD.
JAMES HOWIE KIRKWOOD, B.Sc. (<i>Glasgow</i> .)	HERBERT CHARLES PALAIRET WOOLMER, Stud. Inst. C.E.

(*Paper No. 3008.*)

"Superheated-Steam Engine Trials."

By WILLIAM RIPPER, M. Inst. C.E.

It has long been known that considerable improvement in steam-engine economy might be expected from the use of superheated steam; but up to the present time it has usually been considered that for certain practical reasons superheating was not likely to be generally adopted. The experience of engineers thirty or forty years ago was that superheating was liable to give trouble by the scoring of the valve-faces and the cylinders, and occasionally by the overheating of the superheaters.

When steam of higher pressures and higher normal temperature began to be used, and when at the same time compound engines began to be introduced, it was found that the economy obtainable by superheating might be more easily secured by methods presenting fewer mechanical difficulties. Accordingly engineers have devoted themselves to increasing the range of steam-pressures, and to the development of multiple expansion engines. It will, however, be admitted that with saturated steam the limit of efficiency is nearly reached. It is, therefore, not surprising that engineers should once more revert to superheating, in which direction a large advance on present-day efficiency may be expected, and in fact is now being obtained.

While superheating has been in abeyance in this and most other countries, the engineers of Alsace and the neighbouring district, under the inspiration of the late Mr. Hirn, have devoted much attention to the subject. As a consequence, the use of superheated steam in many parts of South Germany is now becoming common; and the economical results obtained are remarkable. The Author has several times recently visited these districts, and having personally carried out a large number of trials on a superheated-steam plant at the Sheffield Technical School, he now proposes to lay the results before the Institution. The data on this subject at the disposal of English engineers are very meagre, especially with regard to the behaviour of super-

heated steam in the cylinder; and it is with special reference to this latter point that the Author's experiments have been made.

Superheated steam is steam heated above the temperature of saturated steam at corresponding pressures. Superheating, as carried out in ordinary practice increases the temperature and volume of the steam at constant pressure. The change of volume due to superheating was assumed in the experiments described to be proportional to the change of absolute temperature. The specific heat of superheated steam was taken as at constant pressure 0·48, and at constant volume 0·346.

The objects of the trials were :—

(1) To determine the steam-consumption of the engine per I.H.P. per hour, working with various degrees of superheat and at varying loads.

(2) To find to what extent the dryness fraction of the steam during expansion is affected by the superheat; and what degree of superheat (if any within practical limits) would render the steam dry or superheated, at cut-off and at release.

(3) To determine the nature of the heat-exchange between the steam and the cylinder-walls, for varying degrees of superheat.

(4) To derive conclusions which may assist in the future development of superheating.

The Engine (Figs. 1 and 2, Plate 2).—The engine used was a "Schmidt Motor," supplied with highly superheated steam from a Schmidt superheater described later. The motor and the steam-generator were constructed at the works of Messrs. Dingler of Zweibrücken, and were designed to afford about 17 I.H.P. The motor was a horizontal, single-acting, simple, non-condensing engine, somewhat similar in construction to a gas-engine. It consisted of a pair of cylinders of equal diameter with long trunk pistons. The piston-rings were placed well to the front of the piston with the object of keeping them in a comparatively cool zone. The cranks were at an angle of 180° with each other. The cylinders were 7·094 inches in diameter, with a stroke of 11·8 inches. The clearance space amounted to 7 per cent. The piston constant was 0·002355, and the area of clearance surface in each cylinder, 1·946 square foot. The engine had no piston-rods or stuffing-boxes. The valve-gear consisted of two plain piston-valves without spring rings; one valve being the inlet-valve, and the other the exhaust-valve, for both cylinders. The superheated steam was in contact with only a very small portion of the surface of the valves, viz., that about the external middle portion of the

steam-valve and the portion closing the ports of the exhaust-valve. The hollow internal portion of both valves was open to the exhaust-steam chamber at the top and bottom. There were no valve-rods working in stuffing-boxes, but the valves were worked by steel strips which allowed a little spring, to meet the play required by the movement of the lever working the valve from the eccentric-rod.

The engine was regulated automatically by a simple type of shaft-governor, which varied, as required, the position on the shaft of the eccentric driving the inlet valve. The exhaust opening and closing was capable of adjustment by hand, but was kept constant throughout the trials. The piston-valves were turned accurately to fit the cast-iron bush in which they worked, and though not perfectly tight, the leakage was extremely small.

The effect of a leaky inlet-valve would be to allow steam to pass to exhaust without entering the cylinders, and the engine would thus be debited in the weighed exhaust with a higher steam-consumption than was actually the case. Judging from the results, viz., 17·046 lbs. per I.H.P. per hour, at the highest load for a simple non-condensing engine, it did not appear that there was any considerable error from this cause. On starting the engines, there was always a certain amount of leakage past the piston; but this gradually disappeared after the engine had been running a little while. The trials were commenced about an hour after the engine was started, and during this hour, the engine was run more or less under the conditions intended for the day's trial. The leakage round the pistons was greater with saturated than with superheated steam, though it was extremely small at any time. With superheated steam there was usually no appearance whatever of leakage at the pistons.

The steam-consumption being determined by the weighed exhaust, it might be supposed leakage past the piston, though small, would show that the engine was credited with work done in the cylinder by steam not included in the weight debited against the engine. This, however, would probably not be so to any appreciable extent, because, assuming the bore of the cylinder uniform throughout, as was the case, the leakage would be greatest at the highest pressures and where the slowest speed would occur, i.e., before cut-off. But steam leaking past the piston before cut-off would be made up from the boiler, and the weighed exhaust would represent the steam actually used for generating the power in a single-acting engine.

The Boiler and Superheater (Fig. 3, Plate 2).—The appearance of the Schmidt superheated steam generator suggests that it is a simple vertical boiler, unusually small for its power, and provided with a coil of tubes above the boiler around which the flue gases pass on their way to the chimney. The arrangement of the tubes of the superheater is very ingenious. The superheater coils are divided into two series, the bottom two coils being termed the "fore superheater," and the remainder of the coils the "main superheater." The coils are arranged watch-spring like, and are placed one above the other.

The steam left the boiler by a perforated tube in the steam space, entered first the lowest coil and passed on to the one next above it. It then entered the upright chamber (called the after evaporator), and from here it passed direct to the topmost coil of the upper or main superheater. It then flowed downwards through the successive coils in a direction opposite to that of the flow of the chimney gases, and left the superheater at its maximum temperature from the lowest coil of the main superheater (the third coil from the bottom), and passed forward to the engine. By this arrangement the following advantages were secured. 1st. The tubes were protected from injury from the hottest furnace gases, by the passage through them of wet steam at a high velocity. 2nd. The steam in its passage through the main superheater flowed downwards into a zone of temperature much higher than that of the gases entering the chimney, in this way securing a high degree of superheat for the steam, with a comparatively low temperature of chimney gases.

The dimensions of the superheater were:—

Internal diameter of tubes	1½ inch.
External , " , " , " , "	1¾ "
Heating-surface of fore superheater . . .	32.25 square feet.
" , " , main , " , "	143.0 " "
Grate-area	2.6 " "
Effective heating-surface of boiler . . .	37.625 " "
Working pressure of boiler	9 atmospheres.

The boiler, superheater, steam-pipes and engine cylinders were well covered with non-conducting material, capable of withstanding the action of high temperatures. For regulating the superheat, a valve was fixed at the top of the vertical flue tube, which was closed when the maximum superheat was required, and the gases had then to pass through the superheater on their way to the chimney. If it was desired to reduce the superheat, the valve was

raised and more or less of the furnace gases escaped direct to the chimney without going through the superheater-coils. In cases where the chimney gases passed away at a higher temperature than was consistent with reasonable economy, coils might be added above the superheater, to act as a feed-water heater. The application of a Schmidt superheater to a Cornish or Lancashire boiler is illustrated in Fig. 4, Plate 2.

The superheater-tubes are not to be regarded as additional boiler heating-surface; the actual evaporating surface of a Schmidt boiler is, in fact, much reduced, on the principle that the largest portion of the heat is transmitted from the part of the heating-surface nearest the furnace. The remaining heat, instead of acting on an extended evaporating surface, was here employed to superheat the steam. The result attained by this method of applying the heat would show a considerable gain in favour of superheating. Provided the temperature of the gases entering the chimney were no higher in the one case than in the other, there was no difference in the efficiency of the plant as an arrangement for the transfer of heat from the coal to the working fluid.

Suppose, in a suitably-designed plant, 10 per cent. of the heat from the furnace-gases had been employed in superheating the steam instead of evaporating water on an extended heating-surface. The effect would be 10 per cent. less water evaporated per lb. of coal burnt; and the steam generated would carry away to the engine 10 per cent. additional heat as superheat. The relative merits of these two methods of using the heat would be shown to be greatly in favour of superheating. Comparing the set of trials in the 220 load series (pages 94 and 95), all having approximately the same initial pressure on the piston, and being the same in all respects except the degree of superheat supplied in the steam, the results are:—

Trial No.	Degrees F. of Superheat above Saturation Temperature.	Net Heat in Saturated Steam from Temperature of Hot Feed.	Units added as Superheat.	Percentage additional Heat Expended.	Heat-Units Converted into Work.	Net Gain Per cent.
25	0	1,008	0	0	64.23	0
33	98	..	47	4.7	75.3	12.0
16	254	..	122	12.0	108.9	51.4
15	321	..	154	15.2	126.5	70.9

Thus, for an expenditure, on superheating, of 15.2 per cent. of

the heat required to generate saturated steam, the work done would be increased from 64·23 to 126·5—a gain of 97 per cent. If, instead of being used to superheat steam, the 15·2 per cent. had been used on an extended boiler heating-surface, the total heat-units converted into work would have been $64\cdot23 \times 115\cdot2 \div 100 = 74$, or a net gain of $126\cdot5 - 74 = 52\cdot5 = 70\cdot9$ per cent., in favour of using the heat to superheat instead of to evaporate more water. So that, without loss in efficiency of the boiler and superheater as a heat transmitter, in a suitably-designed plant there would be a considerable gain of power (or increase of economy) by superheating, because of the increased power-producing quality of the working fluid supplied.

Regulation of the Superheat.—The regulating arrangements, shown in Figs. 3, Plate 2, consist of a damper, by means of which the hot gases might be either sent through the superheater or diverted from it partially or entirely on their way to the chimney. When the work to be done was fairly constant, very little regulating was necessary, and in ordinary working the temperature of the superheated steam passing through the coils remained remarkably steady.

It was found, in ordinary practice with superheating, if the load on the engine was reduced, the temperature of the steam immediately began to fall, though there was no appreciable change in the condition of the fire; on the other hand, if the load was increased, the superheat of the steam increased also. Similarly, when steam was being raised, while the pressure would gradually rise, and though the hot gases played round the superheater, no superheat would be registered by the gauge until the engine was started and the steam flowed through the superheater coils. If the engine was lightly loaded, the degree of superheat rose slowly; but if the load on the engine was increased, the temperature of the superheater rose more rapidly. From this it appeared that the higher the velocity of the steam passing through the superheater, the more rapidly the heat was taken up by the steam.

The rate of firing no doubt affected the result, as the higher the load, other things being equal, the more steam required and the heavier the firing, and therefore the more heat supplied to the superheater, and *vice versa*; but independently of the condition of the fire, as soon as the steam-supply to the engine was reduced, the temperature of superheat registered by the gauge immediately fell.

When the boiler was too large for its work, it had to be fired lightly, and it was then not possible to obtain any high degree of

superheat. Hence, in most of the light-load trials of the present series, it was found impossible to show results with the highest range of superheats; firstly, because of the light firing, and secondly, because the superheat appeared to be not so rapidly taken up when the weight of steam passing through the superheater was reduced.

The relation between the weight and the velocity of the steam passing through the superheater, and the rate of absorption of heat by the steam, presents a subject for further investigation.

The general arrangement of the appliances used in carrying out the trials is shown in Fig. 5. Regulation of the superheat by mixing with saturated steam was adopted in order to obtain a low degree of superheat. The arrangement shown includes an enlargement of the steam-pipe close to the engine to form a mixing-chamber, with which are connected steam-pipes from the superheater and the supplementary saturated-steam boiler respectively. The relative quantities supplied were regulated by the respective stop-valves.

If the superheater is properly designed and the valve-gear of the engine is suitable for use with superheated steam, then the superheat, being once taken up by the steam, the latter should be preserved at a high temperature by all possible means till it reaches the admission-valve of the engine. If superheated steam is desired at the engine, on no account should this heat be dissipated by returning the steam into the boiler before entering the engine, as is the method adopted in some so-called superheaters.

When the Schmidt motor was tested with saturated steam, the steam-supply had to be obtained from the supplementary boiler referred to, which only worked to 100 lbs. per square inch. This accounts for the fall of initial pressure when saturated steam or low superheats were used.

The reason for the use of the supplementary boiler will be clear when it is remembered that the Schmidt boiler and superheater, to supply an engine of a given power, is much smaller than a boiler supplying only saturated steam for the same power. It has a grate-area only about one-half the usual size. Hence, when it is desired to supply saturated steam only and still maintain the power, this boiler is much too small.

The Brake.—The brake used was a cast-iron drum, 3 feet in external diameter and 10 inches wide on the face, with an internal rim 3 inches deep to hold cooling-water. The drum was keyed on to the shaft. Surrounding the circumference of the drum was a

friction-strap consisting of blocks of oak 10 inches by $2\frac{1}{2}$ inches by $1\frac{1}{4}$ inch, placed with about 3 inches between the blocks and connected by two steel bands. The brake could be thrown in and out of gear or tightened as desired by the arrangement shown in Figs. 5 and 6. An ordinary weighing-machine was placed so that a stop might rest with one end on the weighing-machine while the other end pressed against a notch in the brake-strap. The resistance of the strap was measured directly on the weighing-machine. The radius of the brake-arm, i.e., the length of the perpendicular from the centre of the shaft to the line of resistance of the stop, was 1 foot $8\frac{3}{4}$ inches. The weight of the stop was 30 lbs., and this was deducted from the reading of the weighing-machine.

During the whole of the trials the lever of the weighing-machine was kept floating, the adjustment necessary to tighten or slacken the brake being regulated by the nut shown in Figs. 6. The brake required very little adjustment, owing to the fact that the lubrication was constant and that the brake-rim was kept at a constant temperature. The latter was regarded as important, because variation of temperature would cause a variation in the diameter of the drum, and therefore of its grip upon the brake. The temperature was kept constant by a continuous flow of cooling-water to the brake, and of hot water from it by an arrangement of pipes shown in Fig. 5.

The Indicators.—The indicators used during the trials were one Tabor indicator and one Thompson indicator of large size. The springs were obtained specially for these trials, and they were tested from time to time cold, on an apparatus specially arranged for the purpose. They were found to show readings about 2 per cent. low, a variation from the true pressure which would probably have disappeared if the springs had been tested hot.

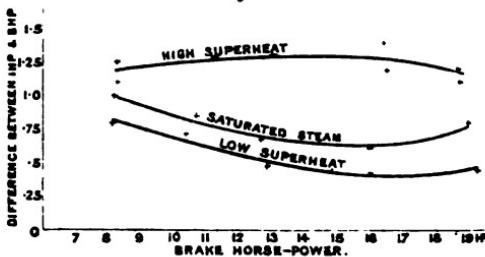
Diagrams were taken every quarter of an hour throughout the trials. It was at first feared that working with superheated steam would interfere with the efficiency of the indicators. Experience showed however that there was no need for concern on this point, if the precaution was observed of removing the indicator piston and spring immediately after each diagram was taken, so as to avoid the possibility of the temperature of the spring rising to a degree which might interfere with its accuracy.

The mechanical efficiency throughout the trials was so remarkably high as to lead to some suspicion of error. The greatest care however was taken, and, it is believed, the results are correct. The weighing-machine was tested for accuracy before and after each

trial. The friction of the engine was necessarily extremely small from the nature of its design ; for there was no slide-valve friction ; no piston-rods nor valve-rods working through stuffing-boxes ; and the main bearings, crank-heads, and eccentric-straps were all fitted with anti-friction metal. The power absorbed in driving the engine (the difference between the indicated and the brake horse-powers) was, for constant speed, nearly uniform for the high superheat series for all loads. The same was true of the saturated steam series and of the low superheat series. The power absorbed was greatest, *Fig. 7*, with the high superheats, least with the low superheats, and intermediate for the saturated steam.

Temperature - Entropy Diagrams. — These diagrams represent quantities of heat by areas, the temperature being the vertical and the entropy the horizontal dimension. Entropy is thus heat-units \div absolute temperature. Gain or loss of heat at constant

Fig. 7.



temperature is represented by an extension of the area from left to right or a contraction of the area from right to left respectively. Gain or loss of heat at constant entropy (as during adiabatic compression or expansion) is represented by an extension of the area upwards or contraction of the area downwards respectively. The temperature-entropy diagram is constructed on the temperature-entropy chart. The method of constructing the chart has been described by its Author, Mr. Macfarlane Gray.¹ It was a great convenience to be able to obtain an accurate chart carefully drawn to a suitable scale, which might be used as a standard, the actual diagram in each case being plotted on tracing-paper. Such a chart was kindly supplied to the Author by Captain H. Riall Sankey, and was used for the whole of the trials.

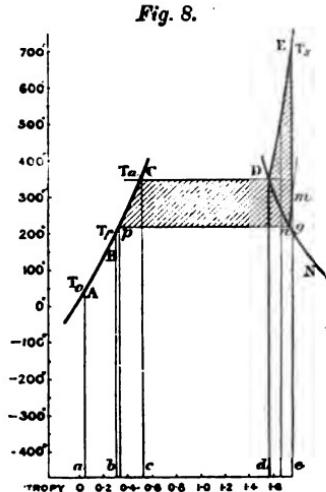
The addition of heat to saturated steam for the purpose of

¹ Proceedings of the Institution of Mechanical Engineers, 1889, p. 399; Minutes of Proceedings Inst. C.E., vol. xcvi. p. 241; Engineering, January 8, 1896.

superheating, and the effect on the heat available for useful work is represented by *Fig. 8*, which is the temperature-entropy diagram for 1 lb. of superheated steam. Starting with the line *a A*, T_0 is the absolute temperature of the cold feed to a convenient scale of temperature; T_1 is the temperature of the hot feed after passing through the feed-heater. The area *a A B b* represents the heat-units taken up by the feed-water in passing through the heater. Therefore the length *a b* represents $(\text{total heat supplied during change from } T_0 \text{ to } T_1) \div (\text{mean temperature during change})$; or *a b* might be obtained from Tables of "entropy." The area *b B C c* represents heat-units given to the feed-water after entering the boiler, to raise it from temperature T_1 to temperature of evaporation T_e . The area *c C D d* is the heat added during evaporation of 1 lb. of water at constant temperature T_e to convert it into steam, and represents the latent heat L_e for 1 lb. of steam at absolute temperature T_e and pressure p_e . The length of the entropy line *c d* is $L_e \div T_e$. The steam is now to be superheated, and its temperature is raised from T_e to some temperature T_s along a constant-pressure line *D E*. The height of T_s depends on the temperature of the steam, and is drawn to the same scale of temperature as before. The quantity of heat Q involved in this

change is $0.48(T_s - T_e)$, where 0.48 is assumed to represent the specific heat of steam at constant pressure. Therefore the length *d e* is $0.48(T_s - T_e) \div (\text{mean temperature between } T_e \text{ and } T_s)$. Assuming adiabatic expansion from T_s along the vertical line *E e*, where the vertical line cuts the dry-steam line *D N*, as at *g*, the steam ceased to be superheated, and if expanded further becomes wet steam. In the case shown in the diagram, the steam is superheated when exhaust opening took place, namely at *m*. The steam follows the constant-volume line through *m n* to the back-pressure line *n p*. The "dry-steam" line *D N* is drawn by taking values from the Tables for $L_2 \div T_2$; $L_3 \div T_3$, &c., at various pressures $p_2 p_3$, &c., and drawing a free curve through the points thus obtained.

The "absolute thermal efficiency" of an engine working under



the conditions herein described, and subject to no losses whatever, is represented by the hatched area $p C D E m n p \div b B C D E e b$. The absolute thermal efficiency of any engine is the ratio of the heat converted into useful work to the total heat supplied.

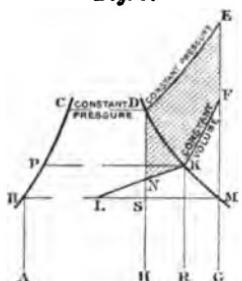
In accordance with the views of Captain H. Riall Sankey, a "standard thermal efficiency" has been added, but pending the further consideration of the subject of a suitable standard of comparison, the efficiency of the Carnot cycle, namely $(T_1 - T_2) \div T_1$, has been taken as the standard of comparison in this Paper. It is improbable that any superheated steam-engine would ever exceed in efficiency the value $(T_1 - T_2) \div T_1$, where T_1 is the temperature of saturated steam at the pressure on entering the engine, and T_2 is the temperature due to pressure in the exhaust-pipe. The Author has considered that superheating might be looked upon as a device

for realizing as far as possible the efficiency of the Carnot cycle, taking temperatures only of the saturated steam.

The efficiency of the superheat *per se*, apart from its practical effect in reducing cylinder-condensation, may be seen by considering the somewhat exaggerated temperature-entropy diagram shown in Fig. 9. Let A B C D H represent the heat contained in 1 lb. of saturated steam at pressure and temperature C, and let H D E G represent the heat added as superheat. Then, if the

superheated steam in the cylinder expanded down to back-pressure B M, the steam at release would be dry saturated steam without any superheat, and the efficiency of the superheat would be $S D E M \div H D E G$. For the case where steam is superheated at release, if the steam in the cylinder at some high temperature E is expanded along the adiabatic line E G to some lower pressure F (at which, however, the steam is still superheated), then, if release takes place, the superheated steam will follow the constant-volume lines F K, K L till it falls to the back-pressure line B L. The efficiency of the superheat is $N D E F K N \div H D E G$, and the loss due to release taking place before the whole of its superheat had been used is S N K F M S. The heat equivalent of these areas can be measured from the temperature entropy chart in heat-units. The constant-volume curve from K is drawn by taking the specific heat of steam at constant volume 0.346, and drawing the curve K F as D E was drawn for constant pressure, substituting 0.346 for 0.48.

Fig. 9.



It will be evident from these diagrams, *Figs. 8 and 9*, that no important gain can be theoretically expected from superheating, the actual gain in practice being due to the more or less complete removal of the loss by cylinder condensation; for when the working fluid is saturated steam, no transfer of heat however small can take place from the steam to the metal without an accompanying deposition in the cylinder of water, which, during the exhaust stroke, is evaporated at the expense of the heat of the cylinder-walls. The result is that the mean temperature of the cylinder-walls with saturated steam is much below that of the steam entering the cylinder.

On the other hand, when the steam is sufficiently highly superheated, it is in a far more stable condition than before the superheat was added, and it can part with the whole of its superheat to the cylinder-walls without undergoing any liquefaction. If the steam contain sufficient excess heat to provide for the heat absorbed by the cylinder-walls, and the heat required to evaporate the water of condensation due to work done upon the piston during expansion, then the steam will be dry at release. A cylinder dry at release parts with little heat to the comparatively non-conducting medium passing away during exhaust, hence the smallness of the heat-exchange between the steam and the cylinder-walls under such conditions. As the superheat is increased, the steam becomes more and more dry at cut-off and at release. The drier the steam at cut-off, the more work is done per lb. of steam passing through the cylinder. The drier the steam at release, the less demand upon the cylinder-walls during exhaust for heat of re-evaporation, and the higher the mean temperature of the cylinder-walls.

Superheating thus removes the principal source of loss of heat in the cylinder, namely, water in the cylinder evaporated at release, and it reduces also to a minimum the heat-exchange between the steam and the cylinder walls.

RESULTS OF THE TRIALS.

The trials are arranged in the Tables, Appendix I, in series, according to the power developed by the engine, and for convenience they are named by the number representing the net load in lbs. on the brake. Thus the "320 load series" refers to the series with 320 lbs. net load upon the brake. The loads varied between 320 lbs., beyond which it was not thought advisable to load the engine, and a net load of 110 lbs. Each series is also arranged in order of the temperature of the steam at constant

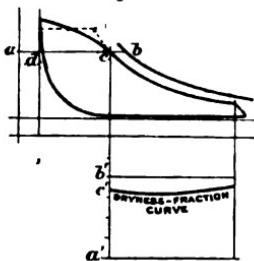
load and constant speed; commencing with saturated steam and gradually rising by successive increases of superheat to a maximum temperature. The trials are also further divided in sets of varying initial pressures expressed in atmospheres, a condition which modified the effect of the superheat.

By degrees of superheat is meant the number of degrees F. of temperature of the steam entering the engine above that normal to its pressure as saturated steam. This temperature was measured at the stop-valve, Fig. 5, Plate 2, by an electrical pyrometer subsequently described. The boiler pressures were recorded by a gauge showing atmospheres and parts of an atmosphere, hence the decimal places in the reading. The gauge recording the pressure of steam entering the engine was compared before and after the trials with a standard gauge and found correct. The number of expansions was measured by dividing the whole volume of the cylinder, including clearance-space, by the volume of the steam in the cylinder at cut-off.

THE INDICATOR DIAGRAMS.

The diagrams shown in Figs. 10 to 39, Plate 3, are arranged in sets according to the brake load, the speed being nearly constant throughout.

Fig. 40.



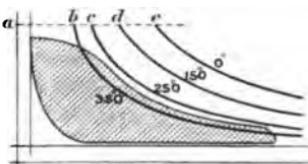
They represent the mean diagram for each trial, which was constructed by measuring a series of ordinates drawn upon the actual diagrams from both the right- and the left-hand cylinder, and taking the means of the ordinates. For this purpose alternate diagrams were selected from those taken during the trial, so that the mean diagram was usually constructed by measuring twelve diagrams from the right and twelve from the left cylinder. The mean diagram was then enlarged to a scale of 20 lbs. to an inch and was photographed down to the reduced scale as exhibited. The mean pressure of the diagrams was measured with an Amsler Planimeter, carefully tested and found correct.

The diagrams are each shown with a saturation curve and a dryness-fraction curve. The saturation curve was drawn by taking a horizontal line through any point *c*, *Fig. 40*, on the expansion curve of the diagram at cut-off or beyond it. Then *a d* is the clearance volume, and *a b* is the volume (from Regnault's

Tables) of the known weight of steam in the cylinder during expansion, supposing it all present as dry saturated steam at pressure c , and including weight of steam enclosed during compression and weight of steam passing through the cylinder per stroke. Also $a c \div a b$ is the dryness fraction. The steam in the clearance space at beginning of compression was assumed to be dry saturated steam. The dryness fraction curve below the indicator diagram is constructed for all points in the expansion-curve from cut-off to release, by setting up from a horizontal line to any scale, the ratio $a' c' \div a' b' = a c \div a b$.

These diagrams, Figs. 10 to 39, Plate 3, show the effect upon the relative positions of the saturated-steam curve and the expansion curve of the indicator diagram as the amount of superheat was varied. Thus, with a constant indicated HP. at constant speed, and therefore a constant area of indicator diagram, but a varying degree of superheat in the steam, the relative weights of steam passing through the cylinder to develop the power were reduced, Fig. 41, from $a e$ lbs. with saturated steam at 0° of superheat to $\frac{a d}{a e}$ lbs. with 150° , to $\frac{a c}{a e}$ lbs. with 250° and to $\frac{a b}{a e}$ lbs. with 350° of superheat.

Fig. 41.



Referring to the actual series of trials (320 load) for the effect of superheat upon steam-consumption, &c.

EXTRACT FROM TABLES, APPENDIX I.

Pressure Entering Engine. Lbs. per Sq. In.	I.H.P.	Superheat. ° F.	Steam per Hour per I.H.P.	Absolute Thermal Efficiency.	Heat-Units Absorbed by Cylinder Walls during Admission.
102.7	19.74	Saturated	38.545	6.56	12.913
97.9	19.59	86.6	34.850	7.04	8.792
130.0	19.76	217.9	20.170	11.34	2.000
131.6	19.85	326.0	17.046	12.84	1.575

These results show that by superheating the steam entering the engine 326° F., the steam-consumption per I.H.P. per hour is reduced from 38.545 lbs. to 17.046 lbs.; or that the same power is obtained for 56 per cent. less steam than when no superheat is used. The heat-units converted into work per lb. of saturated steam were

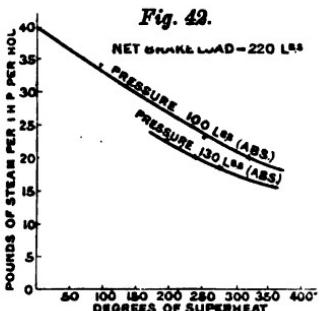


Fig. 42.

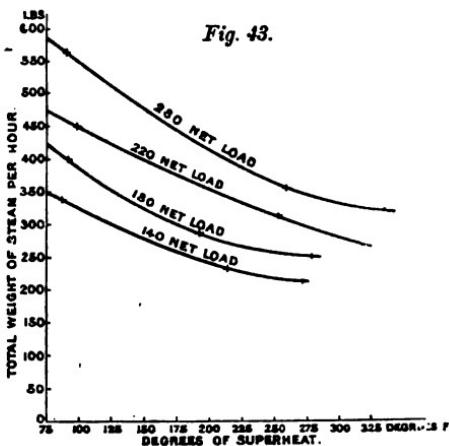


Fig. 43.

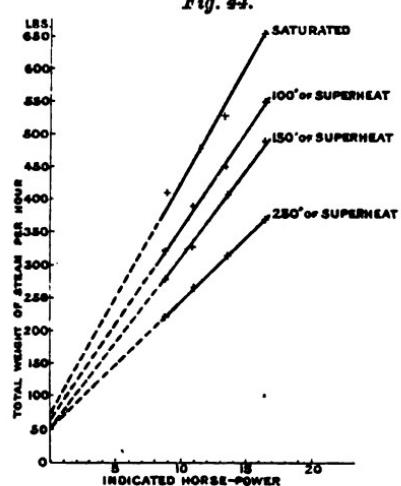


Fig. 44.

66·03 for a net expenditure of 1,005·7 thermal units. The heat-units converted into work per lb. of steam superheated 326°F. were 149·3, for an expenditure of 1,162·76 thermal units. That is for 157·06 thermal units additional, or 15·6 per cent. of superheat, there was a gain of 126 per cent. of work done per lb. of steam, and a rise of absolute thermal efficiency from 6·56 to 12·84 per cent., or an increase of absolute thermal efficiency of 95·7 per cent. A portion of the gain was due to the somewhat higher initial pressures with the high superheat.

The effects of superheating in reducing the rate of steam-consumption as the amount of superheat is increased, are shown in *Figs. 42, 43 and 44*, as well as the further advantage of increased initial pressure, in *Fig. 42*.

It is instructive to notice from the indicator diagrams how rapidly the superheat disappears on admission of the steam to the cylinder, and in how few cases the steam is found to be

superheated at cut-off. This will be observed by the position of the saturated-steam curve relatively to the expansion-curve of the diagram. In nearly all cases, the saturated-steam line was outside the expansion line; in other words, the steam was wet during expansion, notwithstanding that it had been supplied in a more or less highly superheated condition.

In the very few cases in which the steam in the cylinder was superheated at cut-off, the saturated-steam line passed inside the indicator diagram (see Figs. 12, 13, 16, 18, 19, 23, 24, 27, Plate 3), showing that in these cases the steam in the cylinder at cut-off occupied a greater volume than that due to dry saturated steam at the same pressure; in other words, that the steam still retained a portion of its superheat. From these experiments, and for this engine, it appears that unless the degree of superheat of the steam entering the engine reaches at least 200° F. above its normal temperature with a late cut-off—or a still higher degree of superheat for an earlier cut-off—the condition of the steam in the cylinder at cut-off is that of wet steam at the temperature of saturation.

To show the extent of the superheating necessary in these trials to obtain dry steam at cut-off, a selection has been made of trials in which the dryness has approached as nearly as possible to 100 per cent. As the number of expansions increases it becomes increasingly difficult to obtain dry steam at cut-off.

Load Series.	Trial No.	Temperature of Steam Entering Engine.	Degrees above Normal Temperature.	No. of Expansions.	Dryness at Cut-off.
		° F.	° F.		Per cent.
320	5	565	218	2.58	100.3
280	1	612	264	3.28	98.2
280	20	589	261	2.30	104.8
220	9	625	275	4.07	100.5
140	13	613	272	4.59	88.5

It will be seen that the temperature of the steam entering the engine was in no case below 565° F., and this was for a late cut-off; with the earlier points of cut-off, though the temperature of the steam entering the engine was still higher, there was a considerable degree of wetness in the cylinder at cut-off.

In order that the steam in the cylinder might be dry at release—not as the result of re-evaporation, but of high temperature preventing the formation of water in the cylinder during admission and throughout the stroke to the point of release—the

steam entering the engine required to be heated to about 300° F. above the temperature normal to its pressure. In such a case, when the steam was dry at release, it was superheated at cut-off sometimes 100° or more, finally falling at the end of the expansion to the temperature of saturated steam. The highest temperature of the steam in the cylinder at cut-off throughout these trials was 455° F. The temperature of the steam supplied to the engine for the same trial was 667° F. The number of expansions in the cylinder in this latter case was 2.19. For a small increase in the number of expansions, and the same temperature of steam supplied to the engine, the temperature at cut-off rapidly falls; thus for 3.02 expansions the temperature of the steam entering the engine was 654° F.; but the temperature of the steam in the cylinder at cut-off fell to 357°. For 4.07 expansions the temperature of the steam supplied was 625° F., and the temperature at cut-off was 334°.

The following Table is a selection from the general Tables of the cases in which it was found possible to obtain the steam in a superheated condition at cut-off, showing also the condition of the steam at release and the degree of superheating required to obtain these results.

Load Series.	No. of Trial.	Pressure of Steam Entering Engine (Absolute).	Temperatur e of Steam Entering Engine.	Superheat Entering Engine above Normal Temperature.	Superheat at Cut-off.	Dryness at Release.	No. of Expansions.
320	5	139.0	565	217.9	2.34	95.1	2.58
220	9	134.0	625	275.5	10.21	97.4	4.07
280	2	131.0	654	306.3	42.9	98.3	3.02
320	6	131.6	674	326.0	89.1	102.5	2.83
220	10	115.0	671	333.1	53.63	106.5	3.27
280	20	100.9	589	261.1	36.63	97.9	2.80
220	15	99.45	648	320.8	56.75	100.5	2.59
280	19	102.4	667	338.0	150.61	109.2	2.19

It is divided into sections according to the initial pressure of the steam, so that the effect of the superheat alone might be seen without the modifying influence of varying initial pressure.

APPLICATION OF THE TEMPERATURE-ENTROPY DIAGRAM.

The influence of superheat in increasing the efficiency of steam as a working fluid is best shown by the temperature-entropy diagram. These diagrams represent for all cases the work done per lb. of steam expanding in the cylinder, independently of all considerations as to size or power of engine, and show what portion of the available heat in the 1 lb. of steam has been realized in the engine as useful work.¹

The weight of steam expanding in the cylinder includes the steam passing through the cylinder per stroke plus the steam enclosed at compression, which latter has in all cases been assumed dry at exhaust closure.

The portion of the temperature-entropy diagram which is used as the chart, in ordinary cases, is that shown shaded in *Fig. 8*, where $T_0 T_s$ is the "water" line, and $D N$ is the "dry-steam" line. In *Fig. 45*, p. 79, the corresponding lines are shown more nearly vertical and straight because the vertical scale of temperature is much enlarged in the latter *Fig.* relatively to the scale of entropy.

The method of drawing the diagram on the chart is extremely simple if it is desired to represent only the expansion curve of the indicator diagram, as it is only necessary to take a number of points between cut-off and release on the indicator diagram, and to find the dryness fraction $a c \div a b$ of the steam at these points, *Fig. 40*. Then, knowing the pressure and the dryness fraction for each point taken, corresponding points $a b \div a k$, *Fig. 45*, may be located at once upon the temperature entropy chart. In order to transfer points of the indicator diagram other than those on the expansion curve, it is necessary to find the diagram factor.² If the steam expanding in the cylinder weighs exactly one pound, the diagram factor will be 1; but since the actual weight of steam expanding in the cylinder is in these trials less than one pound, it was necessary to find the factor by which the actual weight of steam must be multiplied, in order to express the changes of the indicator diagram on the chart in terms of one pound of steam. Thus:—

Weight of steam enclosed at compression	0·002984
" " " passing through engine per stroke . . .	0·032721
Total	<u>0·035705</u>

Then the diagram factor is 1 divided by 0·035705 = 28.

¹ This diagram differs from the indicator diagram in giving, not the work done per stroke, but that done per lb. of steam.

² Proceedings of the Institution of Mechanical Engineers, Feb. 1894, p. 82.

If now any point on the indicator diagram be taken, and the volume of the steam in the cylinder corresponding with that point be determined, this volume multiplied by the diagram factor gives the position of the point as to volume on the chart; and its pressure being known, its position may be completely determined.

Fig. 46, Plate 3, shows the temperature entropy diagrams for trials at loads 320, 280, 220, 180, 140, in which *saturated steam only* was used. The diagrams are superposed, the one on the other, for the purpose of comparison. The top line of the diagram is the mean initial pressure line of the indicator diagram, obtained as shown by dotted line Fig. 40.

From the trials it will be seen that in this engine using saturated steam the steam-consumption per I.H.P. per hour was less the greater the load, or, in other words, the later the cut-off, thus:—

Trial No.	Net Brake-Load.	Lbs. of Steam per I.H.P. per Hour.	No. of Expansions.	No. of Curve on Diagram, Fig. 46, Plate 3.
69	140	44.750	5.09	1
67	180	41.946	4.08	2
63	220	39.625	3.42	3
64	280	39.567	2.60	4
66	320	38.545	2.13	5

The reason for the improved economy with saturated steam in the case of the higher loads and fewer expansions will be evident from the temperature entropy diagrams, Fig. 46. If the admission pressure and the dryness fraction of the steam were the same for all points of cut-off, then the earlier the cut-off the greater the gain of efficiency by increased expansion, shown by gain of area at release corner. But in these trials this gain is evidently more than neutralized by two other effects, namely, greater dryness of the steam, and higher mean admission pressure as the load on the engine was increased. Curve 1, 1', 1" is the diagram for the minimum load, and 5, 5', 5" that for the maximum load. The intermediate loads are also shown.

If there were no losses whatever in steam-engine cylinders, the diagrams of work done per pound of steam would fill the whole area between the water-line on the left, and the vertical adiabatic line on the right, Fig. 45, and between the upper horizontal line representing the pressure of steam at the engine stop-valve, and the lower horizontal line representing pressure in the exhaust-pipe. The object is to fill the available area on the

chart as much as possible with the actual diagram from the engine. How incompletely this object of filling up the area is attained with saturated steam, and how effectually it is accomplished with superheated steam will be seen on reference to the temperature-entropy diagrams, Figs. 46 to 56, Plate 3.

Referring to *Fig. 45*, it will be seen that (neglecting the effects of compression) there are four conditions which determine the gain or loss in the thermal efficiency of the steam expanding in the cylinder.

(1) The proximity of the mean admission-pressure line *ab* to that of the source from which the steam is supplied.

(2) The condition of the steam in the cylinder as to dryness, in other words, the extent to which the dryness fraction line *bc* of the actual engine diagram shown shaded, approaches the dry-steam line of the chart, enlarging or otherwise the area of the shaded diagram between the water line and the dry-steam line.

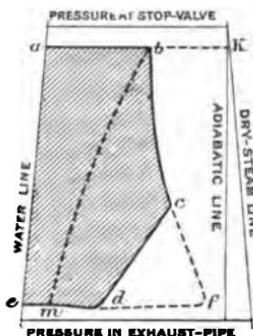
(3) The number of expansions of the steam, or the extent to which the pressure at end of expansion approaches the back pressure. Thus, in *Fig. 45*, the line *cd* represents fall of pressure during release, the fall taking place at nearly constant volume, and following very nearly a constant-volume line of the chart.

When the terminal pressure of expansion was carried down to back pressure, the expansion line *bc* extended to *f*; but as the difference of pressure between that at the end of the expansion and the back pressure became greater, and the release-corner line *cd* receded from the point *f*, the blunter the corner became, the greater the loss of area due to incomplete expansion. When the steam was admitted to the end of the stroke, and the engine worked without expansion, the line *cd* receded to the position shown by the dotted line *bm*, where *bm* is also a line of constant volume.

(4) The nearness of the back-pressure line *ed* to that representing the pressure in the exhaust pipe.

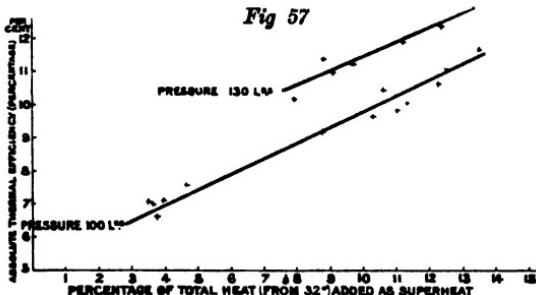
Superheating influences the dryness-fraction line *bc* only, and the sole object of superheating is the extension of the effective work area to the right to cause the line *bc* to coincide with the dry-steam line of the chart, and especially that the release end *c* of the line may reach the dry-steam line. Superheating may therefore be looked upon, not as a means of obtaining a thermal efficiency in any way pro-

Fig. 45.



portional to the temperatures used in the superheat, but as a device for realizing the full thermal efficiency of the saturated steam.

Dry steam at release is obtained, not by the indirect method of re-evaporation, which is a source of great loss of heat; but by the use of highly superheated steam which more or less entirely prevented liquefaction during admission and maintained the cylinder free from deposited water or liquefaction to the end of the stroke. In order to accomplish this result completely, the temperature of the steam admitted to the cylinder had to be sufficiently high to secure a condition of superheat at cut-off, and this effect is shown by the high triangular area on the right of the temperature-entropy diagrams, Figs. 50 to 56, Plate 3, carried to a height depending on the temperature of the steam at cut-off, and representing the extent to which the steam was superheated at cut-off. The diagrams, Figs. 46 to 56, are helpful in discovering where the gains and losses occurred, and they show clearly how effectually the addition



of superheat extended the expansion line of the work diagram from position No. 1 for the saturated-steam trials, further and further to the right, to positions 2, 3 and 4 respectively towards the dry-steam line, filling the whole area more and more as the superheat was increased. In some instances curve No. 4 with the highest superheats, passes outside the dry-steam line as shown.

Comparing trials Nos. 8 and 15, 220 series, Figs. 49 and 55, Plate 3, it may be seen that the steam-consumption per I.H.P. per hour was equal in the two trials, one using high initial pressure and medium superheat, and the other a lower initial pressure and a higher superheat—the exhaust pressure being constant. When these two important factors, a large range of pressure and a high superheat, are combined, Fig. 56, a maximum result is obtained, as in trial 6, load series 320. It follows that anything which tends to lower the initial pressure—as for example a throttling governor—is a source of loss of efficiency.

Considering the expansion-line of these diagrams, and the extent to which they deviate from the vertical adiabatic line, it will be seen that the wetter the steam in the cylinder at cut-off, the greater the flow of heat from the walls to the steam during expansion, that is, the more the expansion line slopes towards the dry-steam line; but the dryer the steam at cut-off, the more nearly the expansion line becomes a vertical line; in other words, the more nearly the cylinder becomes non-conducting. The actual direction of the expansion-line is the resultant effect of two opposite influences proceeding at the same time, i.e., flow of heat from the steam

Fig. 61.

220 LOAD SERIES.

—	Fig. 58.	Fig. 59.	Fig. 60.	Fig. 61.
Trial	15	16	33	25
Degrees of superheat . . .	320·8	253·5	98·26	—
Steam per 1.H.P. per hour	20·077	23·36	33·79	39·62
Percentage of total heat missing at cut-off	8·85	14·4	30·95	40·45

Fig. 60.

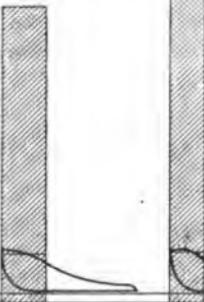


Fig. 59.



Fig. 58.



to the walls as the piston uncovers the cooler end of the cylinder, and flow of heat from the walls to the steam at the hotter end of the cylinder as the pressure and temperature fall during expansion. This action, however, is reduced to a minimum when the steam is dry at release.

HEAT-EXCHANGE DIAGRAMS.

The diagrams, *Figs. 58, 59, 60, 61*, show typical examples of the great influence of superheat in reducing the extent of the heat interchange between the steam and the cylinder-walls, the power and speed being constant.

The rectangles shaded on the indicator-diagram represent the heat given up to the walls during admission of steam to the cylinder, i.e. the heat missing at cut-off. They are drawn to the same scale of heat-units as the indicator-diagram. Their numerical values are given in the Tables, Appendix I.

The heat missing at cut-off is (total heat supplied in the steam per stroke) + (heat in steam enclosed at compression) + (work done upon steam during compression) - (work done during admission) - (heat remaining in steam at cut-off).

The value of the heat missing at cut-off, termed Q_a , was obtained thus:—

Let h_o = heat-units in water at temperature of evaporation t_o , measured from 32° F.

ρ_o = internal latent heat of steam at pressure p_o .

t_s = temperature of superheated steam.

t_n = temperature of saturated steam normal to pressure.

x_1 = dryness fraction of steam at p_1 .

c_p = specific heat of superheated steam assumed = 0.48.

Q = total heat supplied per stroke from 32°.

M_o = weight of steam enclosed at compression.

W_a = work done by steam during admission.

W_d = work done upon steam during compression.

M = weight of steam supplied per stroke.

$A = 1 \div 778$.

Then:—

(1) For steam not superheated at cut-off:—

$$Q + M_o(h_o + x_o \rho_o) + A W_d = A W_a + Q_a + (M + M_o)(h_1 + x_1 \rho_1).$$

(2) For steam superheated at cut-off:—

$$\begin{aligned} Q + M_o(h_o + x_o \rho_o) + A W_d \\ = A W_a + Q_a + (M + M_o) \{ h_1 + \rho_1 + c_p(t_s - t_n) \} \end{aligned}$$

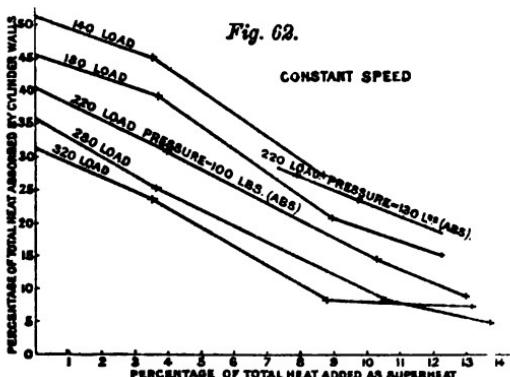
from which Q_a might be obtained.

The value of t_s , the absolute temperature of the superheated steam at cut-off, was obtained by measuring to scale from the clearance line the volume v_s of the steam at cut-off on the indicator diagram; and to the same scale the volume v_n of saturated steam measured to the saturated-steam curve. Then it is assumed that the steam behaves as a perfect gas and expands in proportion to its absolute temperature; and $t_s : t_n :: v_s : v_n$.

Referring to Fig. 62, it appears:—(1) that within the limits of the trials, the higher the degree of superheat in the steam (other things being equal) the less the fraction of the heat absorbed

by the cylinder-walls during admission. (2) That for a given degree of superheat and with varying cut-off and constant initial pressure, the earlier the cut-off, or in other words, the lower the load, the greater the loss of heat to the cylinder-walls during admission. (3) That if the initial pressure is increased, the power developed remaining the same, the heat lost to the walls during admission is increased. This result follows from (2), and is confirmed by experiment.

The speed was maintained as nearly constant as possible throughout the whole series, except in one set, namely, trials 21, 22, and 23—see concluding columns of the Tables, Appendix I—in which it is shown that (the conditions being the same in all



other respects) with varying revolutions and a constant power exerted:—

- (a) The mechanical efficiency of the engine decreases as the speed increases.
- (b) The steam-consumption per I.H.P. per hour is lower as the speed increases.
- (c) The steam-consumption per brake H.P. per hour is practically constant at all speeds within the limits of the trials.
- (d) The percentage dryness at cut-off increases as the speed increases.
- (e) The heat given up to the cylinder-walls decreases as the speed increases.

The number of revolutions were recorded by a counter attached to the engine. The feed-tank from which the feed-water was pumped, rested on the table of a weighing-machine. The smallest feed-pump, worked very slowly, was too large for the work; an

overflow-pipe and regulating-valve were fitted to the delivery-pipe of the pump to return excess water to the feed-tank. The steam used by the feed-pump was supplied from an independent boiler, and the weight so used was not accounted for in the results. The feed-water was passed through a feed-water heater on its way to the boiler, Fig. 5, Plate 2. The weight of exhaust steam condensed was carefully obtained by the arrangement shown in Fig. 5, Plate 2. This weight was in all cases less than that pumped into the boiler — the difference averaging about 5 per cent. The weight of steam used per I.H.P. per hour was in all cases calculated from the weighed exhaust steam.

Equivalent Dry Saturated Steam. — The weight of steam used per I.H.P. per hour, though a convenient standard of comparison, is not always satisfactory, because it takes no account of the differences of total heat initially contained in the steam supplied. These differences are very small with saturated steam within the ordinary limits of pressure, but with superheating they become considerable. Thus the total heat from 32° F. per lb. of saturated steam at 50 lbs. absolute pressure is 1,167, and at 150 lbs. it is 1,190, while the total heat of steam at 150 lbs. pressure superheated 300° is 1,334; and, since it is the heat that does the work and not the steam, the weight of steam used, as a measure of relative efficiency, is somewhat misleading. It is also conceivable that a steam-engine could be worked without any actual consumption of steam, as has been suggested by Mr. S. R. Chatwood, of Bolton, who proposed to use the steam as a gas, and to work the engine with the superheat only. When reduced consumption of water is of as much importance as reduced consumption of coal, as is the case in some parts of the colonies, the low feed-water consumption with superheated steam is of importance *per se*, and should be credited to the superheated steam-engine.

To remove the objection which might reasonably be taken to the statement of the results only in lbs. of steam actually used, these results have, for the Tables, all been reduced to the equivalent weight of dry saturated steam.

The equivalent dry saturated steam was obtained thus: if H_1 denotes the heat-units from feed temperature actually supplied per lb. of superheated steam, H_2 the total heat of saturated steam at the same pressure, and from the same feed temperature, and W the actual weight of steam used per I.H.P. per hour, then—

$$\text{The equivalent dry saturated steam} = W \times H_1 \div H_2.$$

The weight of cooling-water passing through the condenser was so regulated that its temperature should not attain a point at which vapour would visibly arise from the surface of the tanks. The weight of this water was measured by the rise or fall of the water-level in a glass tube, fixed against a scale of lbs. of water previously carefully graduated. The weight recorded was in each case corrected for the difference between the temperature of the water and that at which the scale was graduated.

COMPOUND ENGINES WITH SUPERHEATED STEAM.

It will be observed that the results given in the present series of trials have been obtained with a single-acting, simple, non-condensing engine. Much better results would of course follow the use of superheated steam in compound-condensing engines, as has been shown in trials conducted by Prof. Schröter of Munich, who obtained remarkably good results with a compound engine using superheated steam in the first cylinder only.¹ If the steam were supplied superheated to the successive cylinders of multiple-expansion engines instead of to the first cylinder only, a still further considerable increase of economy would follow.

When highly superheated steam is supplied only to the first cylinder, the whole of it may appear in that cylinder as steam; but when it passes forward to the next cylinder, only about 70 per cent., or less, will appear as steam, the remainder being present as water if there is no superheating between the cylinders. The power of the lower-pressure cylinder is therefore much reduced as compared with the power in the high-pressure cylinder. Superheating between the cylinders would restore the balance of power, and would add considerably to the power of the lower-pressure cylinders for a given weight of steam supplied to them.

Dimensions of an Independent Superheater between the Cylinders.—Assuming the steam exhausted from the first cylinder to be in the same condition in regard to wetness as that supplied in the first instance by the boiler; the heat required to be transmitted to the steam by the second superheater would be approximately the same as that transmitted by the first superheater. But the steam passing through the second superheater being less dense, its capacity would require to be larger than that of the first superheater.

If an independent furnace were used to heat this second super-

¹ Quoted by Prof. W. C. Unwin in his "James Forrest" lecture, Minutes of Proceedings Inst. C.E., vol. cxxii. p. 177.

heater, its fuel-consumption would require to be between 10 per cent. and 15 per cent. of that used by the original furnace to generate saturated steam. It will be observed that as the steam-pressure falls, the temperatures to be dealt with for a given percentage addition of superheat fall also.

Admission of a Supplementary Supply of Superheated Steam between the Cylinders.—If drying and superheating the exhaust-steam, on its way from the high- to the low-pressure cylinder, could be accomplished by the admission of an auxiliary feed of highly superheated steam from the main steam-pipe to the receiver, it might be supposed that the loss would be more than compensated by the increased efficiency of the steam in the following cylinders. But it may be seen that this proposal, though often made, is not feasible; for, assuming the auxiliary steam supplied from the main steam-pipe to contain 10 per cent. additional heat as superheat; then, if the steam in the receiver contains 10 per cent. of moisture, the weight of auxiliary feed necessary even to dry the steam without any superheating, would be equal to the total weight of steam exhausted into the receiver from the first cylinder—an altogether impracticable quantity.

Lubrication.—The difficulties arising from defective lubrication in the earlier applications of superheated steam were probably due to the fact that the lubricant—or at least that portion of it admitted to the valve-chest, where it would be subjected to the maximum temperature of the steam—had all its lubricating properties destroyed, when its presence was more harmful than otherwise. But, with the greatly improved quality of the lubricants now to be obtained, and with increased attention to the method of application of the lubricant, this cause of trouble has been entirely removed; and the experience of the large number of continental steam-users who now employ highly superheated steam is that lubrication is no longer a difficulty. The lubricant used throughout the trials described in this Paper was “Valvoline” oil. It was fed to the engine by mechanical lubricators consisting of a ram forced very slowly into the oil-chamber by a worm-and-wheel mechanism. The oil entered the steam-pipe by a small tube in front of the entrance to the valve-chest. The lubrication caused no trouble, and no more oil was used with superheated than with saturated steam.

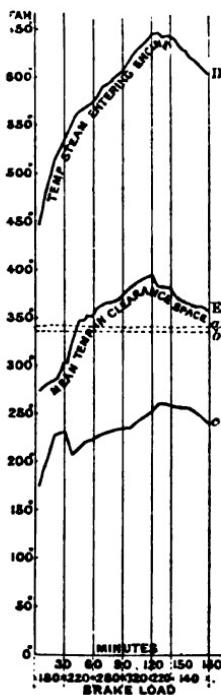
Mean Temperature in the Cylinder.—Fig. 69 shows the result of an experiment to determine the mean temperature of the cylinder-walls at varying loads and degrees of superheat. For this purpose

the couple of the pyrometer was inserted directly into the clearance-space of the cylinder. The engine was run at constant speed, and the pressure of the steam was maintained constant. The temperature of the steam at the stop-valve of the engine (line D), and the temperature in the clearance-space (line E) were read every five minutes. The readings commenced with a light load (180 lbs.) on the brake and a low superheat, the firing being brisk with a view to gradually increase the superheat. The trial was conducted for half-an-hour, the temperature gradually rising. The load was then increased to 220, and a further run of half-an-hour was made; the temperature of the entering steam and of the cylinder-walls being meantime gradually increased. Half-hourly trials with gradually increasing loads were continued until the maximum load was reached, when the loads were decreased, and the temperatures fell. From these trials it will be seen that the mean temperature of the internal surface of the cylinder-walls never reached 400° F., though the temperature of the steam passing through the stop-valve attained 645° .

Temperature Measurements.—The pyrometer installation, Fig. 64, Plate 2, consisted of a Le Chatelier dead-beat galvanometer G, supported in a large camera-box raised from the concrete floor by brick pillars P which prevented vibration. The source of light was a 5 candle-power incandescent lamp L. The lamp-box carried an adjustable lens fitted with a square diaphragm crossed by a very fine platinum wire, and focussed on the scale S which was divided in millimetres, the distance of the scale from the mirror being 10 feet. The deflections of the mirror were caused by the currents set up in the circuit, due to the difference of temperature between the cold junction and the place where the temperature was being measured.

The leads of the couples placed in the various parts of the boiler and engine led into the cold-junction tubes T, which contained alcohol and were surrounded by melting ice, the whole of the

Fig. 63.



Line a = temperature of saturated steam at boiler pressure.
.. b = temperature of saturated steam at stop-valve pressure.

.. c = difference of temperature between D and E.

cold junctions being placed in a box B. On the top of this box a number of binding screws connected the couple leads to the leads which carried the various currents to the galvanometer. A switch K was placed at the galvanometer end of the installation, so that each couple might in turn be put in circuit with the galvanometer. This pyrometer was very carefully calibrated from time to time by inserting the couple in melting ice, boiling water, thick cylinder-oil and boiling sulphur, its readings being checked by a standard thermometer. The temperature of the feed-water and circulating water was taken with thermometers checked against the standard.

CONCLUSIONS.

The trials recorded show that the use of superheated steam opens a wide field for improvement in steam-engine economy. To obtain the full advantage of superheating, the temperature should be raised sufficiently high to secure dry steam in the cylinder throughout admission and up to release, for which purpose the steam should be supplied at a temperature of about 650° F. at the engine. With steam at this temperature used in a simple non-condensing engine, the same power was obtained for less than half the steam required when no superheat was used. It was found from the trials that as the temperature of the superheat in the steam was increased, the increased economy in steam-consumption which followed was also accompanied by a proportional reduction in the extent of the heat-exchange between the steam and the cylinder-walls. With the highest superheats and the highest economies, the heat-exchange became remarkably small, the cylinder-walls approaching the condition of being almost perfectly non-conducting.

The practical difficulties supposed to be associated with the production and use of highly superheated steam may be (in fact have been) satisfactorily overcome. Experience has shown that the superheater-tubes, after long periods of severe work, show no signs of burning, scaling or injury of any kind. With the greatly improved quality of lubricating oils, and with proper attention as to the judicious application of the lubricant at the working parts, no trouble arises in the lubrication of superheated steam-engines. Having once obtained highly superheated steam in the superheater, great care should be taken, by the use of suitable non-conductors, to maintain the high temperature of the steam in its passage to the engine-cylinders. The best results in these trials

were obtained in association with a high range of pressure in one cylinder and a late cut-off. Any cause which tends to increase initial condensation in the cylinder with saturated steam, tends also with superheated steam to absorb the superheat, and to neutralize its useful effect in the cylinder. The superheated steam supplied to an engine retains its superheat up to and surrounding the admission-valve; but when it is admitted to the cylinder, it immediately parts with its superheat to the cylinder-walls. Unless the steam is superheated at least 200° F. above its normal temperature, and in some cases still higher, depending on the number of expansions, it parts with the whole of its superheat to the walls, and the steam in the cylinder is no hotter than saturated steam at the same pressure. Hence, unless the steam is sufficiently highly superheated before entering the cylinder, it is not dry even at cut-off; therefore the fear of difficulty with lubrication in the cylinder is somewhat unnecessary. Superheated steam at high temperatures may be safely and advantageously used in double-acting engines. Many such engines are now at work and in course of construction.

The chief point to be considered in the design of an engine to work with highly superheated steam, is the steam-admission arrangements. Evidently, the steam-admission valve, being subjected to the maximum temperature of the steam, should be practically frictionless, so as to remove the necessity for concern about its lubrication. The piston-valve without spring-rings, accurately turned and ground to fit a cast-iron bush, is satisfactory for small powers. For larger powers, various types of equilibrium-valve gears are successfully employed. The ordinary flat slide-valve is not a satisfactory type for use with a high degree of superheat, unless the pressure in the valve-chest is low.

The Author desires to express his indebtedness to Mr. William Radcliffe of Sheffield, by whose kindness the superheater plant was placed at his disposal; to Prof. J. O. Arnold for the use of his delicate pyrometer installation; to Mr. F. K. Preston, Stud. Inst. C.E., who performed the bulk of the arithmetical calculations; to Mr. E. H. Crapper, who was responsible for the temperature measurements; and to all others who assisted in the trials.

The Paper is accompanied by numerous Tables, reproduced in Appendixes I and II, and by 65 drawings, from which Plates 2 and 3 and the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.—TABLE I.

	320 Load Series.			300 Load Series.		
	6 Atmospheres.	8 Atmospheres.	6 Atmospheres.	8 Atmospheres.	6 Atmospheres.	8 Atmospheres.
No. of trial	23	35	6	27	34	4
Date of trial	11/2/96	25/2/96	18/10/96	21/2/96	11/0/96	6
Duration of trial	6	3	6	3	6	6
Net load on brake	320	320	320	320	300	300
Degrees of superheat	Saturated	86°.6	917°.9	526°.0	300	527°.7
Barometric pressure	14.7	14.6	14.8	14.6	14.5	14.54
Boiler pressure (absolute)	107.7	107.7	138.7	138.6	130.24	138.8
Pressure of steam entering engine (absolute)	102.7	91.9	130.0	131.6	98.53	131.8
Cylinder pressure (mean absolute during admission)	84.6	108.6	114.1	88.8	82.1	114.2
Number of expansions	2.13	1.9	2.58	2.83	1.98	2.63
Mean effective pressure, right cylinder	46.48	44.65	45.55	46.05	44.93	42.85
" " left cylinder	45.22	45.12	48.0	47.4	42.93	45.47
Mean effective pressure for both cylinders	45.85	44.88	46.77	46.73	43.94	44.16
Absolute mean pressure	68.7	68.8	66.726	66.37	63.8	64.0
Revolutions per minute						
Piston speed	182.86	185.32	179.42	180.4	185.94	189.84
Indicator H.P.	359.63	364.48	352.87	354.79	365.99	356.86
Brake H.P.	19.74	19.68	19.56	19.55	18.82	18.82
Mechanical efficiency	95.78	97.87	93.92	94.0	95.88	93.25
Absolute I.H.P.	28.72	28.72	28.16	28.2	27.94	27.27
Feed water used (total)	Ibs.	"	"	"	"	"
" Temperature " per hour	"	49.8	47.9	46.16	383.84	2.350
" Temperature " before heater	"	49.8	47.9	46.16	58.17	21.10
Weight of steam condensed (total)	Ibs.	4,668.5	2,018.0	3,393.0	1,861.95	2,018.0
" " " per hour	"	58.74	54.56	50.17	4,200.0	1,780.25
" " " per I.H.P. per hour	"	40.2	38.1	21.47	18.34	40.49
" " " per B.H.P. per hour	"	26.49	23.43	14.16	12.0	28.3
Equivalent dry saturated steam per L.H.P. per hour	"	74.5	74.7	69.72	67.1	71.8
Steam per absolute I.H.P. per hour	"	"	"	1.8	4.0	"
Temperature of condensed steam	"	"	"	"	"	3.35
Steam missing	"	"	"	"	"	3.7
Weight of cooling water passing through condenser (total)	Ibs.	160,000	40,160	64,304	89,660	89,520
" " " per hour	"	16,666.7	3,386.7	9,050.6	7,210.9	14,520.0
" " " (corrected for temperature)	"	16,667.0	13,388.0	9,019.0	7,186.0	14,587.0
" " " (per lb. of condensed steam)	"	21.83	19.81	22.6	21.23	12,037.0
Initial temperature of condensing water	"	"	"	"	"	24.6
Final "	"	"	"	"	"	24.43

TABLE II.

	260 Load Series.				8 Atmospheres.			
	6 Atmospheres.				8 Atmospheres.			
No. of trial		26	32	19	1	1	2	
Date of trial		5/2/96	21/2/96	10/1/96	9/10/95	9/10/95	9/10/95	
Duration of trial	hours	6	3	6	6	6	6	
Net load on brake	lbs.	280	280	280	280	280	280	
Degrees of superheat	°F.	148	14.4	14.9	15.0	14.38	14.2	
Barometric pressure	lbs. per sq. inch	107.4	94.67	100.9	102.4	104.6	107.3	
Boiler pressure (absolute)	"	102.3	90.6	87.3	87.3	103.5	103.0	
Pressure of steam entering engine (absolute)	"	89.2	2.08	2.3	2.19	111.2	110.1	
Cylinder pressure (mean absolute during admission)	"	2.6				3.26	3.02	
Number of expansions	"							
Mean effective pressure, right cylinder	lbs. per sq. inch	39.99	40.05	41.63	42.28	42.74	40.45	
" " " left cylinder	"	39.98	38.86	39.21	39.0	40.71	41.99	
Mean effective pressure for both cylinders	"	39.985	39.45	40.43	40.64	41.72	41.22	
Absolute mean pressure	"	61.1	60.5	60.4	59.9	62.37	60.87	
Revolutions per minute								
Piston speed	feet per minute	175.86	175.66	172.63	173.5	181.5	186.66	
Mean I.H.P.	"	345.86	345.27	339.63	341.22	355.31	355.96	
Brake H.P.	"	16.56	16.32	16.44	16.6	17.75	17.62	
Mechanical efficiency	"	15.92	15.9	15.83	15.7	16.35	16.43	
Absolute I.H.P.	per cent.	98.11	97.4	93.07	94.57	92.12	93.21	
25.3	25.03	24.47	26.84	26.84	26.84	26.84	26.84	
Feed-water used (total)	lbs.	"	"	2.231.0	2.042.0	1.955.0	1.955.0	
" " per hour	°F.	48.4	52.8	57.8	54.0.3	52.92.33	52.92.33	
Temperature of feed-water, before heater	"	[205.8]	203.2	204.7	52.3	69.19	61.03	
After heater	lbs.	3,831.6	1,693.0	2,132.2	1,838.6	2,018.2	1,868.37	
Weight of steam condensed (total)	"	655.27	684.3	355.37	323.08	338.37	311.66	
" " per hour	"	59.67	52.57	21.67	19.46	18.95	17.68	
per I.H.P. per hour	"	41.16	36.49	25.75	20.57	20.57	18.95	
per B.H.P. per hour	"	25.89	22.56	23.94	21.01	19.92	19.92	
Equivalent dry saturated steam per I.H.P. per hour	"	72.16	71.6	65.3	70.37	12.68	11.97	
Steam per absolute I.H.P. per hour	op. per cent.	"	"	4.4	6.05	4.62	4.5	
Temperature of condensed steam	"							
Steam mixing	"							
Weight of cooling water passing through condenser (total)	lbs.	82,015.0	35,220.0	40,820.0	37,540.0	62,070.0	47,080.0	
" " " per hour	"	12,869.0	11,740.0	6,803.3	6,256.0	8,618.33	7,846.6	
(corrected for temperature)	"	13,620.0	11,698.0	6,776.8	6,234.1	8,641.1	7,818.4	
(per lb. of condensed steam)	"			19.07	19.29	25.7	25.1	
Initial temperature of condensing water	"	40.2	41.67	40.91	41.4	65.26	65.22	
Final	"	90.5	90.7	88.5	90.4	90.28	91.08	

Temperature of steam on leaving superheater due to pressure entering engine	673.0	770.0	685.0	763.0
" " of steam on entering engine (actual)	329.1	323.6	329.9	347.7
Heat added as superheat . . . . .	..	412.7	588.0	654.0
Total heat (from 32°) for absolute pressure entering engine . . . . .	..	42.76	126.33	147.02
Percentage of total heat (from 32°) added as superheat	1,163.4	1,160.6	1,183.1	1,188.0
Heat supplied per lb. (from feed-temperature) . . . . .	..	3.63	10.7	10.66
B.T.U. per cent.	1,165.9	1,202.66	1,289.7	1,324.34
B.T.U. per cent.	100	100	100	100
B.T.U. per cent.	107.4	150.4	162.2	161.7
B.T.U. per cent.	13.6	12.61	12.68	12.21
B.T.U. 1,008.5	..	1,052.16	1,127.52	1,182.64
Heat converted into work per lb. of steam	64.32	73.61	117.75	134.31
Heat carried away in condensed steam (from feed-temperature) . . . . .	..	6.53	6.11	9.88
Heat given up to feed-water	24.1	18.8	15.6	12.6
Net heat supplied	2.07	1.96	1.72	0.95
Net heat supplied	888.1	927.87	946.5	899.6
Heat not accounted for	76.18	77.17	71.87	69.84
Absolute thermal efficiency	32.0	31.87	67.3	73.73
$T_1 - T_2$; when T_1 = temperature of saturated steam at pressure entering engine	6.37	2.45	5.22	6.57
$T_1 - T_2$; when T_1 = temperature of saturated steam at pressure entering engine	6.37	6.95	10.44	11.25
Standard thermal efficiency (see page 70)	45.2	51.1	75.1	79.8
Volumes of steam enclosed at compression . . . . .	..	..	..	..
Volume of steam at beginning of compression	0.01079	0.01079	0.01079	0.01079
Weight of steam enclosed at beginning of compression	16.6	16.6	16.6	16.6
Weight of steam enclosed at compression ($= V$)	0.04201	0.04066	0.04201	0.04066
Weight of steam enclosed at compression ($= V$)	0.002984	0.002988	0.002984	0.002988
Weight of steam enclosed at compression ($= V$)	3.209	3.0933	3.209	3.0933
Work done upon steam during compression	0.328	0.336	0.319	0.328
Work done upon steam during compression	0.03106	0.03106	0.017149	0.016517
Weight of steam passing through engine per stroke . . . . .	..	32.74	22.4	20.885
Heat supplied per stroke from $S^2 = Q$ = during admission . . . . .	..	0.034034	0.029365	0.020133
Sum of weights of steam so and that passing per stroke	76.4	68.0	72.6	90.0
Absolute pressure of steam at cut-off . . . . .	..	218.16	214.7	214.3
Value of A_1 at cut-off . . . . .	..	818.0	820.88	821.16
Percentage dryness at cut-off	57.4	74.3	104.8	119.5
Degrees of superheat at cut-off . . . . .	..	..	36.63	160.61
Temperature of steam at cut-off (normal) . . . . .	..	..	305.17	304.79
Product of sum of weights of steam $\times \{A_1 + p_1 + C_p (T_e - T_n)\}$	25.45	26.17	341.8	455.4
Absolute work done during admission in heat-units . . . . .	..	..	..	19.94
Heat missing at cut-off = Q_a heat-units	1,498	1,778	22.41	21.6
Percentage dryness at release	67.8	8.22	1.792	1.736
" of total heat supplied missing at cut-off	36.23	26.12	97.9	109.2

TABLE III.

	220 Load Series.						
	6 Atmospheres.			7 Atmospheres.			8 Atmospheres.
No. of trial	25	33	15	10	7	8	9
Date of trial	4/2/96	21/9/96	9/12/95	25/11/95	6·5	6	6
Duration of trial	6 hours	3	6	5	5	5	5
Net load on brake	100. lb.	220	220	220	220	220	220
Degrees of superheat	Saturated of 14·8	235·5	320·8	333·1	395·6	240·5	275·5
Barometric pressure	14·4	14·4	14·4	14·4	14·38	14·24	14·69
Boiler pressure (absolute)	107·6	104·3	105·1	122·32	137·53	131·88	140·88
Pressure of steam entering engine (absolute)	101·7	98·5	99·45	100·5	130·5	131·0	134·0
Cylinder pressure (gauge absolute during admission)	88·4	82·4	84·0	98·8	110·5	113·7	116·4
Number of expansions	3·42	2·67	2·64	2·59	3·27	4·38	4·07
Mean effective pressure, right cylinder	32·1	34·01	33·98	33·73	32·08	31·75	34·63
" " left cylinder	32·03	30·7	31·16	30·99	32·42	34·74	32·92
Mean effective pressure for both cylinders	31·84	31·4	32·6	32·48	33·08	33·23	33·775
Absolute mean pressure	61·4	61·6	51·9	51·7	61·95	63·5	52·8
Revolutions per minute	177·8	180·22	175·44	176·39	179·66	182·73	181·64
Piston speed	349·68	354·44	345·04	346·91	353·14	359·47	360·5
Indicated H.P.	13·33	13·33	13·47	13·49	13·99	14·31	14·45
Brake H.P.	12·64	12·82	12·47	12·54	12·77	13·0	12·94
Mechanical efficiency	94·85	96·17	92·04	92·98	91·39	90·82	81·41
Absolute I.H.P.	21·62	21·9	21·44	21·48	21·97	23·03	22·69
Feed-water used (total)	...	...	1,995·0	1,731·5	1,472·0	2,208·0	1,823·0
" " per hour	...	...	322·5	298·5	294·4	339·65	303·83
Temperature of feed-water, before heater	48·5	61·1	50·2	54·1	64·9	54·16	60·02
" " after heater	100. lb.	100. lb.	100. lb.	100. lb.	100. lb.	100. lb.	100. lb.
Weight of steam condensed (total)	3,169·6	1,351·25	1,888·0	1,226·25	1,318·75	2,109·0	1,729·25
" " per hour	638·27	450·42	314·67	270·87	283·35	324·4	238·21
Per I.H.P. per hour	39·62	35·8	25·36	20·08	18·63	23·64	18·6
Per B.H.P. per hour	41·78	35·14	25·22	21·69	20·82	24·93	20·8
Equivalent dry saturated steam per I.H.P. per hour	24·65	35·17	25·8	22·74	21·41	24·47	20·7
Steam per absolute I.H.P. per hour	69·7	68·2	64·7	62·93	67·5	65·8	64·4
Temperature of condensed steam	oF.	oF.	oF.	oF.	oF.	oF.	oF.
Steam mixing	...	...	...	...	...	...	...
Weight of cooling water passing through condenser (total)	62,340·0	28,380·0	36,160·0	31,240·0	26,140·0	45,880·0	35,140·0
" " per hour	10,390·0	9,453·3	6,020·0	6,208·67	5,228·0	7,058·4	5,886·66
(corrected for temperature)	" "	" "	" "	5,198·0	5,269·2	7,033·0	6,838·6
(per lb. of condensed steam)	10,385·0	9,419·3	6,998·0	19·16	19·78	21·0	20·23
Initial temperature of condensing water	41·0	42·0	44·1	44·54	45·9	49·41	47·42
Final " "	92·7	89·9	91·06	90·5	92·1	91·78	91·3
Steam mixing	...	...	...	...	...	...	...

Temperature of steam on leaving superheater		°F.	328.79	326.5	320.5	165.0	165.0	182.0	612.0	679.0	742.0
" due to pressure entering engine			424.76	580.0	648.0	611.0	643.0	583.0	547.4	349.5	349.5
" Head of steam on entering engine (actual)			47.16	121.68	163.98	169.9	93.89	115.3	63.9	62.8	62.8
" Head added as superheat			1,181.5	1,181.5	1,181.5	1,181.5	1,181.5	1,181.5	1,188.0	1,188.0	1,188.0
Total heat (from 35°) for absolute pressure entering engine			3.99	10.28	13.93	13.49	7.9	9.7	11.12	11.12	11.12
Percentage of total heat (from 35°) added as superheat											
Heat supplied per lb. (from feed-temperature)											
" " " B.T.U.			1,185.7	1,288.96	1,283.79	1,317.58	1,322.79	1,258.99	1,281.14	1,302.88	1,302.88
" " " per cent.			100	100	100	100	100	100	100	100	100
" " " B.T.U.			157.7	149.1	156.1	160.3	161.9	158.4	158.8	154.97	154.97
" " " per cent.			13.53	12.33	12.16	12.16	12.24	12.38	12.39	12.66	12.66
" " " B.T.U.			1,068.0	1,089.86	1,127.68	1,187.38	1,160.37	1,100.49	1,123.34	1,137.71	1,137.71
" " " per cent.			64.23	75.3	108.94	136.48	135.18	112.39	126.69	136.84	136.84
" " " B.T.U.			6.51	6.24	8.48	9.6	10.22	8.93	9.89	10.61	10.61
" " " per cent.			21.2	19.5	19.5	13.2	8.98	12.5	11.64	14.38	14.38
" " " B.T.U.			1.62	1.36	0.99	1.0	0.87	1.0	0.91	1.1	1.1
" " " per cent.			855.6	855.6	895.17	880.3	916.13	898.48	933.67	71.67	71.67
" " " per cent.			73.39	76.59	76.73	68.82	69.08	71.52	69.35	71.92	71.92
" " " B.T.U.			87.07	42.16	110.77	137.3	12.97	71.37	95.63	53.92	53.92
" " " per cent.			6.75	3.48	8.63	10.12	7.79	5.67	7.46	4.06	4.06
" " " B.T.U.			6.37	7.1	9.65	10.93	11.64	10.21	11.29	15.02	15.02
" " " per cent.			0.143	0.110	0.140	0.141	0.163	0.162	0.163	0.164	0.164
$T_1 - T_2$; when T_1 = temperature of saturated steam at pressure entering engine			44.5	50.7	69.4	77.5	76.1	63.0	69.2	73.4	73.4
Standard thermal efficiency (see page 70)											
Volume of steam enclosed at compression			16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Volume of steam at beginning of compression			0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709
Weight per cubic foot at beginning of compression			0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086	0.04086
Weight of steam enclosed at compression ($= 10$)			0.00288	0.00288	0.00288	0.00288	0.00288	0.00288	0.00288	0.00288	0.00288
Value of $(h_a + p_o) \times w$ for steam at pressure at beginning of compression			3.0963	3.0963	3.0963	3.0963	3.0963	3.0963	3.0963	3.0963	3.0963
Work done upon steam during compression			0.318	0.323	0.308	0.303	0.312	0.314	0.320	0.313	0.313
Weight of steam passing through engine per stroke			0.02476	0.026827	0.01486	0.012179	0.01222	0.01479	0.01306	0.01232	0.01232
Heat supplied per stroke from 35° = Q = during admission			29.27	25.67	18.48	17.08	16.44	18.96	17.01	16.27	16.27
Sum of weights of steam w and passing per stroke			0.02764	0.023707	0.01753	0.01567	0.0151	0.0167	0.01594	0.0152	0.0152
Absolute pressure of steam at cut-off			76.0	64.6	62.8	64.4	70.5	91.0	95.5	95.0	95.0
Value of p_1 at cut-off			217.8	286.8	284.98	286.6	280.9	290.8	294.4	294.4	294.4
ρ_1			318.4	325.96	322.23	326.98	315.9	308.3	305.8	305.8	305.8
Percentage of dryness at cut-off			63.16	68.16	94.3	107.48	105.55	77.8	84.3	100.0	100.0
Degrees of superheat at cut-off = $t_c - t_{a_n}$			..	..	..	56.76	53.63	..	..	323.89	323.89
Temperature of steam at cut-off (normal)			..	..	..	287.15	311.37	..	..	334.1	334.1
Product of sum of weights of steam $\times (p_1 + p_o)$ ($p_1 + p_o$)			19.78	19.76	18.65	18.65	17.56	16.93	16.16	16.16	16.16
Absolute work done during admission in heat-units			1.084	1.314	1.228	1.408	1.246	1.246	0.893	0.893	0.893
Heat missing at cut-off = Q heat-units			17.84	79.15	2.806	2.512	7.645	5.19	4.077	4.077	4.077
Percentage dryness at release			70.9	91.1	93.6	100.5	100.5	92.2	96.2	96.2	96.2
" of total heat supplied missing at cut-off			40.45	30.95	14.4	8.85	10.0	27.37	23.61	23.61	23.61

TABLE IV.

	150 Load Series.			140 Load Series.		
	6 Atmospheres.			7 Atmospheres.		
	6 Atmospheres.			7 Atmospheres.		
No. of trial	29	36	18	12	31	14
Date of trial	12/9/96	16/2/96	7/1/96	29/11/95	13/2/96	13
Duration of trial	6 hours	6	6	3	3	6
Net load on brake	180	180	180	180	180	140
Saturated °F.	97.6	188.5	277.2	303.7	316.5	275.1
Degrees of superheat	14.6	14.6	14.9	14.5	14.8	14.4
Barometric pressure	100.0	107.3	108.7	121.7	124.3	106.5
Boiler pressure (absolute)	104.2	101.7	102.2	118.7	115.8	102.5
Pressure of steam entering engine (absolute)	83.4	88.8	88.8	98.8	83.8	84.0
Cylinder pressure (mean absolute during admission)	4.08	3.63	3.36	4.03	3.94	6.03
Number of expansions	•	•	•	•	•	4.89
Mean effective pressure, right cylinder	lbs. per sq. inch	26.94	27.4	28.44	28.14	28.58
" " left cylinder	" "	26.93	26.6	25.52	26.18	25.81
Mean effective pressure for both cylinders	" "	48.6	46.2	46.5	46.97	45.92
Absolute mean pressure	" "	" "	" "	" "	41.15	40.3
Revolutions per minute	•	•	•	•	•	42.07
Piston speed	feet per minute	360.08	348.65	351.61	180.94	180.91
Indicated H.P.	•	11.0	11.04	11.16	11.55	11.58
Brake H.P.	•	10.65	10.32	10.4	10.53	10.53
Mechanical efficiency	•	92.66	93.42	93.24	91.58	91.02
Absolute I.H.P.	•	20.09	19.29	19.54	19.63	20.03
Feed-water used (total)	lbs.	•	•	•	•	•
Temperature of feed-water, before heat exch.	°F.	50.6	52.76	53.6	49.8	55.59
Weight of steam condensed (total)	lb.	[204.2]	189.8	202.4	200.6	204.19
after heat exch.	°F.	206.15	1.738	1.532	1.610	2.00.0
per hour	per hour	482.30	401.87	288.7	253.6	268.37
per I.H.P.	per hour	41.26	36.59	36.95	38.95	37.98
Equivalent dry saturated steam per I.H.P. per hour	per B.H.P. per hour	45.27	38.95	37.98	34.26	35.27
Steam per absolute I.H.P. per hour	•	23.99	20.83	14.81	24.83	25.32
Temperature of condensed steam	°F.	68.8	66.6	65.7	63.13	64.43
Steam mixing	per cent.	•	•	7.4	6.1	5.8
Weight of cooling water passing through condenser (total)	lbs.	62,100.0	23,808.0	34,440.0	29,720.0	30,400.0
per hour	" "	10,380.0	7,938.0	5,740.0	4,836.6	5,780.0
(corrected)	" "	10,313.0	7,908.6	6,719.3	4,919.0	5,759.2
for temperature	" "	"	"	"	5,047.4	5,988.7
Weight of cooling water passing through condenser (per lb.)	°F.	21.38	19.67	19.74	19.0	20.96
of condensed steam	°F.	42.04	39.72	42.5	43.0	47.9
Initial temperature of condensing water	°F.	90.48	90.5	88.86	89.6	87.8
Final	" "	"	"	"	89.58	90.3
Weight of cooling water passing through condenser (total)	lbs.	62,100.0	23,808.0	34,440.0	29,720.0	30,400.0
per hour	" "	10,380.0	7,938.0	5,740.0	4,836.6	5,780.0
(corrected)	" "	10,313.0	7,908.6	6,719.3	4,919.0	5,759.2
for temperature	" "	"	"	"	5,047.4	5,988.7
Weight of cooling water passing through condenser (per lb.)	°F.	21.38	19.67	19.74	19.0	20.96
of condensed steam	°F.	42.04	39.72	42.5	43.0	47.9
Initial temperature of condensing water	°F.	90.48	90.5	88.86	89.6	87.8
Final	" "	"	"	"	89.58	90.3
Weight of cooling water passing through condenser (total)	lbs.	62,100.0	23,808.0	34,440.0	29,720.0	30,400.0
per hour	" "	10,380.0	7,938.0	5,740.0	4,836.6	5,780.0
(corrected)	" "	10,313.0	7,908.6	6,719.3	4,919.0	5,759.2
for temperature	" "	"	"	"	5,047.4	5,988.7
Weight of cooling water passing through condenser (per lb.)	°F.	21.38	19.67	19.74	19.0	20.96
of condensed steam	°F.	42.04	39.72	42.5	43.0	47.9
Initial temperature of condensing water	°F.	90.48	90.5	88.86	89.6	87.8
Final	" "	"	"	"	89.58	90.3

Temperature of steam on leaving superheater	op.	..	..	601.0	720.0	658.0	763.0	..	670.0	745.0
" due to pressure entering engine	"	331.6	328.6	329.0	328.8	641.0	337.9	329.39	329.35	340.9
" of steam on entering engine (actual)	"	419.25	617.9	608.0	650.0	641.0	416.84	634.0	634.0	613.7
Heat added as superheat	B.T.U.	43.99	1,181.9	1,182.2	1,182.3	1,185.3	1,182.4	41.99	103.44	130.61
Total heat (from 32°) for absolute pressure entering engine	"	1,182.7	1,181.9	1,182.2	1,182.3	1,185.3	1,182.4	..	1,185.2	1,185.8
Percentage of total heat (from 32°) added as superheat	"	..	3.72	7.65	11.33	8.96	12.37	..	3.56	8.72
Heat supplied per lb. (from feed-temp.ature)	B.T.U.	1,164.2	1,205.14	1,262.08	1,298.4	1,267.89	1,304.69	1,162.43	1,203.19	1,265.14
" per cent.	B.T.U.	100	100	100	100	100	100	100	100	100
" per cent.	B.T.U.	163.7	147.06	161.9	160.6	157.8	145.35	160.63	146.8	163.2
" per cent.	B.T.U.	13.2	12.2	13.02	12.37	12.45	11.14	12.96	12.2	12.11
" per cent.	B.T.U.	1,010.5	1,058.99	1,090.18	1,137.8	1,110.09	1,159.34	1,011.2	1,111.34	1,134.81
Net heat supplied	"	69.93	98.03	104.5	109.7	122.43	56.87	67.21	103.26	111.26
Heat converted into work per lb. of steam	"	6.18	7.83	8.82	8.65	9.38	4.89	6.59	8.08	8.64
Heat carried away in "condensed steam" (from feed-temp.)	B.I.U.	18.3	13.85	13.1	13.33	8.84	6.17	15.13	11.8	9.17
Heat carried away in "condensed steam" (from feed-temp.)	B.I.U.	1.67	1.15	1.05	1.02	0.69	0.42	1.3	0.98	0.48
" per cent.	B.T.U.	920.2	915.25	895.3	866.45	863.57	922.75	879.77	878.95	878.95
" In circulating water per lb. of steam	B.T.U.	76.77	76.36	73.0	68.19	67.56	68.87	74.29	69.54	68.07
" per cent.	B.T.U.	49.43	63.79	124.67	135.09	132.95	64.23	64.6	120.74	138.16
Heat not accounted for	"	4.26	4.49	5.1	9.6	10.65	6.56	4.33	9.84	10.7
Heat supplied from 32°	"	6.0	8.99	10.06	9.88	10.06	6.02	6.36	9.8	9.83
Absolute thermal efficiency	T ₁ - T ₂	0.144	0.141	0.143	0.143	0.153	0.143	0.143	0.153	0.155
T ₁ - T ₂ : when T ₁ = temperature of saturated steam at pressure	op.	..	..	..	..	..	..	..	..	..
Standard thermal efficiency (see page 70)	op.	41.6	46.9	62.9	70.3	64.2	69.0	39.3	44.5	60.1
Volume of steam enclosed at compression	op.	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709
Pressure of steam at beginning of compression	op.	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Weight per cubic foot at beginning of compression	lbs.	0.04066	0.04066	0.04066	0.04066	0.04066	0.04066	0.04066	0.04066	0.04066
Weight of steam enclosed at compression (= w)	op.	0.02938	0.02938	0.02938	0.02938	0.02938	0.02938	0.02938	0.02938	0.02938
Value of (P ₁ + P ₂) × w for steam at pressure at beginning of compression	op.	3.0963	3.0963	3.0963	3.0963	3.0963	3.0963	3.0963	3.0963	3.0963
Work done upon steam during compression	B.T.U.	0.0336	0.0318	0.0319	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
Weight of steam passing through engine per stroke	op.	0.02195	0.01889	0.0135	0.01166	0.01126	0.01109	0.01106	0.01106	0.01106
Heat supplied per stroke from 32° = Q = during admission	op.	25.96	23.16	17.184	16.487	15.95	14.76	22.52	18.23	13.05
Sum of weights of team w and passing per stroke	op.	0.02483	0.02177	0.01638	0.014646	0.01523	0.01397	0.02193	0.01859	0.0136
Absolute pressure of steam at cut-off	lbs.	74.4	70.0	69.2	75.2	81.0	80.0	73.6	70.0	82.0
Value of h ₁ at cut-off	op.	216.36	211.4	215.28	215.28	214.4	214.4	214.7	212.2	219.6
" P ₁ " at cut-off	op.	819.46	822.7	822.26	820.34	814.9	815.8	820.82	814.2	817.0
Degrees of superheat at cut-off = t _c - t _a	op.	48.8	69.2	84.29	95.05	87.7	96.56	43.2	53.9	88.5
Temperature of steam at cut-off (normal)	op.	..	..	..	..	..	..	..	..	..
Product of sum of weights of steam X (h ₁ + x ₁ P ₁) C _p (t _c - t _a)	op.	16.79	16.53	15.81	15.52	16.185	14.966	1.8	13.365	12.57
Absolute work done during admission in head-units	B.T.U.	0.923	0.911	1.21	1.027	0.983	0.991	1.1574	0.649	0.692
Heat missing at cut-off = Q _a head-units	op.	11.779	9.755	3.768	9.556	3.205	2.219	11.53	8.066	0.793
Percentage dryness at release	op.	65.9	76.3	90.5	95.3	92.4	100.0	67.9	78.9	93.1
" of total heat supplied missing at cut-off	op.	46.37	39.43	21.92	15.21	20.64	10.03	51.35	45.22	27.1

TABLE V.

	110 Load Series.			Revolution Series.		
	6 Atmospheres.	8 Atmospheres.	7 Atmospheres.	21	22	23
No. of trial	30	24	14 1/36	15/1/96	15/1/96	16 1/1/96
Date of trial	13/2/96	22/1/96	6 26	6	6	6
Duration of trial	3	110	110	290	273	244
Net load on brake	lbs.	10-0	10-0	24-9	24-5	24-0
Degrees of superheat	o F.	14-8	14-8	14-3	14-3	14-3
Barometric pressure	lbs. per sq. inch	106-67	141-74	126-39	124-3	124-04
Boiler pressure (absolute)	"	102-3	131-4	116-16	115-24	115-24
Pressure of steam entering engine (absolute)	"	81-0	97-0	102-8	101-3	101-19
Cylinder pressure (mean absolute during admission)	"	4-89	6-73	2-93	3-01	3-19
Number of expansions	"	"	"	"	"	"
Mean effective pressure, right cylinder	lbs. per sq. inch	18-166	18-15	41-18	39-18	37-52
" " left cylinder	"	18-684	17-94	40-64	38-98	34-14
" " for both cylinders	"	18-425	18-22	41-21	39-07	35-83
Absolute mean pressure	"	37-8	38-2	60-9	58-3	55-1
Revolutions per minute	"	"	"	"	"	"
Piston speed	feet per minute	181-02	161-35	170-72	188-5	188-5
Indicated H.P.	lb.	386-01	384-78	317-13	335-78	370-73
Brake H.P.	o F.	7-85	7-74	15-7	15-9	15-9
Mechanical efficiency	per cent.	6-44	6-41	15-117	15-07	14-97
Absolute I.H.P.	per cent.	81-05	82-97	94-6	95-91	93-48
Feed-water used (total)	lb.	16-1	16-22	23-13	23-44	24-46
Temperature of feed-water before heater	o F.	"	1,904	2,128	2,084	2,016
after heater	"	55-6	382-6	384-6	346-67	336-67
Weight of steam condensed (total)	lb.	[203-9]	49-8	50-0	50-3	50-5
" " "	lb.	1,110-87	203-1	203-3	198-3	204-1
" " "	lb.	310-29	1,807-0	2,042-26	2,000-0	2,000-5
" " "	lb.	"	344-19	338-71	333-4	333-4
" " "	lb.	47-14	64-43	21-76	21-76	20-96
" " "	lb.	"	67-52	63-67	22-15	22-13
" " "	lb.	"	"	44-83	23-81	23-81
Equivalent dry saturated steam per I.H.P. per hour	lb.	"	"	21-21	14-95	13-63
Steam per absolute I.H.P. per hour	o F.	22-98	64-8	67-13	65-87	66-77
Temperature of condensed steam	per cent.	"	"	6-09	4-4	3-9
Steam missing	"	"	"	"	"	"
Weight of cooling water passing through condenser (total)	lb.	24,895	32,090	38,190	38,100	37,270
" " "	lb.	8,208-34	6,106-6	6,383-3	6,350-0	6,211-67
" " "	lb.	8,118-7	6,084-6	6,380-4	6,327-1	6,189-2
Temperature of condensing water	o F.	22-09	17-68	18-69	18-96	18-66
Final	"	42-5	40-91	42-2	41-78	41-5
	"	89-88	90-29	90-4	90-17	90-7

Temperature of steam on leaving superheater	670.0	678.0	667.0
" due to pressure entering engine	339.1	339.1	338.0
" of steam on entering engine (actual)	363.0	685.0	678.0
Heat added as superheat	9.12	116.59	115.2
Total heat (from 32°) for absolute pressure entering engine	1,188.1	1,185.3	1,186.5
Percentage of total heat (from 32°) added as superheat	0.77	9.84	9.73
Heat supplied per lb. (from feed-temperature)	1,179.42	1,283.89	1,281.7
" " " " " " "	100	100	100
B.T.U.	147.4	161.5	159.8
per cent.	12.72	13.7	11.92
B.T.U.	1,011.3	1,123.39	1,128.9
per cent.	53.98	67.22	121.4
B.T.U.	4.66	4.85	4.48
per cent.	9.2	11.33	16.2
B.T.U.	0.8	1.46	1.26
per cent.	899.1	972.94	913.88
B.T.U.	77.6	74.02	71.38
per cent.	49.02	70.43	77.95
B.T.U.	6.23	6.97	6.03
per cent.	6.33	6.68	10.75
Heat not accounted for	0.143	0.163	0.153
Absolute thermal efficiency	37.2	34.5	30.3
$T_1 - T_2$; when T_1 = temperature of saturated steam at pressure entering engine	37.2	34.5	30.3
Standard thermal efficiency (see page 70)	37.2	34.5	30.3
Volume of steam enclosed at compression	0.0700	0.0709	0.0709
Pressure of steam at beginning of compression	16.0	16.6	16.0
Weight per cubic foot at beginning of compression	0.04066	0.04066	0.04066
Weight of steam enclosed at compression ($= w$)	"	"	"
Value of $(h_w + p_w)$ \times for steam at beginning of compression	0.00288	0.00288	0.00288
Work done upon steam during compression	3.0963	3.0963	3.0963
Weight of steam passing through engine per stroke	0.311	0.342	0.326
Heat supplied per stroke from $sp = Q$ during admission	0.0705	0.0159	0.0163
Sum of weights of steam at cut-off	20.15	19.03	21.79
Absolute pressure of steam at cut-off	"	"	"
Value of h_1 at cut-off	"	"	"
Percentage decrease at cut-off	"	"	"
Temperature of steam at cut-off (normal)	"	"	"
Product of sum of weights of steam $\times (h_1 + x_{p1})$	"	"	"
Absolute work done during admission in heat-units	"	"	"
Heat missing at cut-off = Q , heat-units	"	"	"
Percentage dryness at release	"	"	"
of total heat supplied missing at cut-off.	"	"	"

APPENDIX II.

BOILER AND SUPERHEATER TRIAL.

Date of trial	June 19, 1896
Duration of trial	7·2 hours
Effective boiler-heating surface	87·625 square feet
Heating surface of superheater (total)	175·25 "
Grate area	2·6 "
Ratio of grate area to boiler-heating surface = superheater surface =	1:14·47 1:67·4
Analysis of "coal—Carbon	78·91 per cent.
Hydrogen	5·67 "
Moisture	5·62 "
Ash	3·29
Calorific value	13,772·5 T.U.
Analysis of coke—Carbon	87·25 per cent.
Hydrogen	2·05 "
Moisture	1·81 "
Ash	5·44
Calorific value	13,668·8 T.U.
Calorific value of mixed fuel { coke = 80·6 % } { coal = 19·4 % }	13,689·8 "
Moisture in mixed fuel	2·5 per cent.
Ash	5·02 "
Carbon value of dry fuel	0·94
Weight of fuel used per hour	45·87 lbs.
" dry fuel used per hour	44·62 "
" ash and clinker per hour	4·16 "
Percentage of ash and clinker	9·0
Dry fuel fired per square foot grate per hour	17·1 lbs.
" per 1.H.P. per hour	3·88
Feed-water per hour	262·19
" temperature before heater	66·37 °F.
" after heater	185·6 "
Evaporation of water per lb. of fuel fired from feed temperature	5·71
Evaporation of water per lb. of dry fuel from feed temperature	5·87
Equivalent evaporation per lb. of dry fuel from and at 212°	6·22
Equivalent evaporation per lb. of carbon from and at 212°	6·616
Steam pressure by gauge	119·5 lbs.
Temperature of steam due to pressure	340·74 °F.
" leaving superheater	755·0 "
" of furnace gases under superheater	884·0 "
" of chimney gases	587·0 "
" of metal tube (bottom coil)	612·0 "
Analysis of chimney gases—CO ₂	7·01 per cent.
O	13·63 "
N	79·34 "
Heat utilized for generating steam per lb. of dry fuel	6,059·6 T.U.
" for superheating per lb. of dry fuel	44·2 per cent.
Total heat utilized	1,166·9 T.U. 8·5 per cent.
Efficiency of combined boiler and superheater	7,226·5 T.U. 52·8 per cent.

Discussion.

Mr. J. WOLFE BARRY, C.B., President, said that, apart altogether Mr. Wolfe from the great interest and importance of the subject of the Paper, Barry. the members, he was sure, would realize the extreme care which had been bestowed by the Author upon its preparation and in the complete and beautiful diagrams placed upon the walls to illustrate it. He felt convinced that he was speaking in the name of the members in tendering to Professor Ripper their grateful thanks for his contribution.

Professor W. RIPPER hoped the members would accept the Paper Professor Ripper. as one intended to bring before them the behaviour of superheated steam in a single-acting cylinder. It was surprising to find the very high temperature of superheat that had been necessary in order to reach the point where steam should be dry throughout expansion. It appeared that a temperature of about 200° above its normal was required in the cylinder to obtain dry steam at cut-off, and 300° to obtain dry steam at release. By the use of that valuable diagram, for the practical applications of which the Institution was perhaps more indebted to Captain Sankey than to any other member, it had been possible to show the effect of gradual increase or decrease of superheat. The remarkable way in which the superheat increased the shaded area of *Fig. 45*, p. 79, and spread it out until it filled the whole figure, between the two extreme lines, as seen in *Figs. 55 and 56*, Plate 3, deserved special attention. Superheating had had a very bad reputation, and a good deal of difficulty and trouble had followed, in the old days, its use; but the business of engineers was to overcome difficulties, and the mechanical difficulty of the mastery of superheat, to make it do what it could do if it was properly used, was a problem to be solved in the future. The results obtained from his experiments, although made in one cylinder, were not only illustrative of the action of superheat in one cylinder, but also of its action in any number of successive cylinders; because, all the cylinders of a multi-cylinder engine might be considered as separate, working with different initial pressures and back pressures.

Captain H. RIALL SANKEY emphasized the growing importance of Captain Sankey. superheating and thought that, as not enough was known about it, at any rate in England, careful attention should be given to

Captain any account of reliable experiments dealing with that subject. Sankey. Except in some comparatively trifling matters, as the testing of indicator-springs cold and the leakage past the piston, he could find no fault with the methods employed by the Author. On page 64 a Table was given in which was exhibited the improvement in steam consumption effected by various degrees of superheating in comparison with saturated steam. The results quoted obviously applied only to the experiments under review, but the paragraph of which the Table formed part did not make that point quite clear, and it might be assumed that superheat could give, under any circumstances, an increased economy of about 70 per cent. But however well the particular engine experimented with might be designed for working with superheated steam, it was evident that the excessive amount of clearance surface, owing to the piston-rings being so far forward, made the engine a very bad one for saturated steam. For confirmation upon that point it would be seen from Table III that in trial No. 25, in which saturated steam was used, the feed-water was 39.6 lbs. per I.H.P., whereas in one of Mr. Willans' trials¹ made with a simple engine working under the same conditions as to admission and exhaust pressures, the consumption was 29.7 lbs. per I.H.P. Again, referring to Table III it would be seen that the standard thermal efficiency of the Schmidt engine in trial 25 was only 44.5 per cent.; that was, the engine was only doing 44.5 per cent. of what was possible, whereas the Willans engine was doing 71.6 per cent. If, however, compound engines working between the same pressures were considered, taking another of Mr. Willans' trials, the water consumption went down to 24.5 lbs. per I.H.P., and that was more like the figure upon which the data for the improvement due to superheat ought to be based. In trial No. 6, where the consumption per I.H.P. was given at 17.05 lbs., each pound of feed-water was supplied, according to the Author's figures, with 1,163 B.T.U. per pound, or 19,800 B.T.U. per I.H.P. per hour. Taking another of Mr. Willans' trials, the consumption was 20.35 lbs. per I.H.P., and the heat per pound was 1,007 units, or 20,500 B.T.U. per I.H.P. per hour. The improvement due to superheat, comparing those two trials, was thus only 3½ per cent.—a very different figure from 70 per cent. It had been found by the Author that 200° F. of superheat were necessary to obtain dry steam at cut-off; but Captain

¹ Minutes of Proceedings Inst. C.E., vol. xciii. The trials quoted were,
 S $\frac{80}{3.2}$, C $\frac{190}{3.6}$, C $\frac{180}{4.8}$

Sankey thought that this must be due to the enormous clearance surface of the Schmidt engine. With an engine better designed in that respect 100° F. might be sufficient. Again, taking the trial of Mr. Willans last referred to, the quantity of steam missing at cut-off was given as 11.7 per cent., and it was thus probable that the initial condensation amounted to 10 per cent. If this condensation were eliminated by means of 100° F. of superheat the consumption would diminish to 18.3 lbs. But the steam would have to be supplied with 1,053 B.T.U. per lb., or the B.T.U. per I.H.P. per hour would be 19,300, as against 20,500, or an economy of 6 per cent. in favour of superheated steam. It was stated in the Paper that the leakage past the piston was more noticeable with saturated than with superheated steam. That was very likely, but the leakage might have been there all the same: being superheated it would not be seen. He did not quite follow the argument in which it was said that the steam actually used by the engine was measured, notwithstanding the leak. The warning given about indicators, namely, the necessity of taking out the springs between each observation, suggested that those indicators which had outside springs might be more suitable for work with superheated steam. He was glad to see that the Author used 778 as Joule's equivalent instead of 772. He should like to ask whether there was a film of oil on the top of the measuring tanks, as this prevented evaporation. He did not understand the statement that the weight of water "was in each case corrected for the difference of temperature between the water and that at which the scale was graduated." The necessity of maintaining the superheat up to the engine had been pointed out by the Author, but it was not evident how that was to be done in cases where there were long ranges of steam pipes.

Professor W. C. UNWIN congratulated the Author on having had Professor Unwin. an opportunity of carrying out experiments with superheating extending to so high a range of temperature, and on the evident care with which they had been conducted. It unfortunately happened that in speaking at a meeting of the Institution the remarks made almost necessarily fell in the direction of criticism. He did not know, however, that it was unfair, because the Author had had the opportunity of saying the best he could for his own views; and the science in which they were all interested could best be advanced by frankly indulging in criticism. He would premise that anything he might say in the way of criticism would only touch upon fundamental and important points. The first and most fundamental objection which he had to the Paper was its

Professor Unwin. title, "Superheated-steam engine trials." That, like several other things in the Paper, was far too general and vague. If the title had been "Trials of superheated steam in a small non-compound non-condensing and non-jacketed engine," the meaning and value of the experiments would have been much more obvious. The objection, he thought, was fundamental. Throughout the Paper results were stated with a generality which was misleading; and it was only when they were restricted to the particular case under examination, that they could be confidently accepted. The Author had complained that the information as to superheated steam accessible to English engineers was very meagre. There were really a score of Papers on superheated steam containing, so far as he knew, everything in the Paper (except what was peculiar to a very small engine), even in the English language; and he hoped the Author did not reflect upon the education of English engineers to the extent of implying that Papers written in French and German were not accessible to them. It was perhaps the more necessary to direct attention to that point because he held in his hands a Paper¹ which had appeared within the last few months on the Schmidt engine, by a German engineer, containing accounts of experiments on a 15-horse, a 20-horse, a 30-horse, a 60-horse and a 100-horse Schmidt engine, on both condensing and non-condensing engines; and even on an engine in which the steam was not only superheated before it entered the high-pressure cylinder but was re-superheated before entering the low-pressure cylinder. It was a matter of regret that not only must an engine capable of using very highly superheated steam be at present obtained only from Germany, but for the best information about highly superheated steam one still had to go to Papers manufactured in Germany. It was shown in the Paper that even in the case of a very small and very bad steam-engine, there was a large economy due to the use of superheating. But even with the best possible engine the economy was much larger than Captain Sankey was prepared to admit. There were three experiments in Professor Gutermuth's Paper, in which an engine not more than 100 HP. worked with a consumption of 10·4 lbs. and 10·6 lbs. of steam per I.H.P. per hour. There was no compound engine of any type not using superheated steam which approached that consumption. It should be borne in mind what the Author had been experimenting with; a small non-condensing, non-jacketed, and non-

¹ Zeitschrift des Vereines Deutscher Ingenieure, vol. xxxx. 1896, pp. 1390, 1417.

compounding engine. It used with ordinary saturated steam, 40 lbs. of steam per I.H.P. per hour, and it was provided with a boiler which apparently had an efficiency of only 52 per cent., and only evaporated 6 lbs. of water per lb. of coal from and at 212°. That should be borne in mind before generally applying the results obtained. In the first page of the Paper it was stated, that, "with saturated steam the limit of efficiency is nearly reached. It is, therefore, not surprising that engineers should once more revert to superheating, in which direction a large advance on present day efficiency may be expected and in fact is now being obtained." The great prejudicial loss in the working of a steam-engine was of course the action on the cylinder-wall. That might be neutralized by compounding, by steam-jacketing, by speed and by superheating. No one of those methods except superheating would entirely annul all cylinder-wall action, and superheating would only do it if it was carried to a degree which he did not think would be found convenient or desirable in practice. Probably in the development of steam-engines more than one of those methods would have to be adopted for annulling the action of the cylinder-wall. It was therefore more important to consider what additional efficiency could be obtained by superheating, in an engine, where compounding, or jacketing, or sufficient speed had already been doing something towards annulling the action of the cylinder-wall. In that case the very high temperatures mentioned by the Author would not be necessary. There was one difficulty in the use of highly superheated steam which had not been alluded to in the Paper, or in other Papers, but which would prove of some importance, if any attempt were made to use steam of a temperature above 600°; that was a very considerable diminution of the strength of some of the material used in the construction of the boiler and engine at those high temperatures. There was one point which he should be glad to have made more clear. In Fig. 4, Plate 2, was given a drawing of a Lancashire boiler with a Schmidt superheater superposed. He had studied the drawing, but found it impossible to make out the direction taken by the furnace gases. It looked as if it were placed in the uptake of the boiler, beyond the external flue. If so, it was in an extremely bad position, and he did not believe that a superheater so placed would work properly. In Professor Gutermuth's Paper there was a similar drawing of a Lancashire boiler in which the superheater was shown in a proper position—so placed that the furnace gases passed from the internal flues of the boiler direct into the superheater and from the superheater into the external

Professor Unwin.

Professor flues of the boiler. He felt sure that successful superheating Unwin. could not be obtained unless the superheater was placed, not as it was in the very early days, in the uptake of the boiler, but much nearer the furnace, where the gases were much hotter and where the smoke difficulty was much less, coating the superheater with soot. The Author had given some explanation of the temperature entropy diagram, and certain formulas in which he had introduced what he had called the "mean temperature" of the steam. That was very misleading. No doubt the term was used in a sense which involved no error; but there were all sorts of "means." The mean temperature intended was not, as might be supposed, the mean of the initial and final temperatures, which would be wrong. He could not conceive why this mode of statement was used instead of the accurate one given in all the text-books. He did not sensibly differ from the use made by the Author of the Carnot measure of efficiency. He had on several occasions pointed out that the proper use of superheated steam was really to annul the cylinder-wall action. It really neutralized part of the waste in the engine, not raising the temperature range. It was right then in calculating the efficiency of an engine with superheated steam to take T_1 as the temperature of saturated steam at the point of cut-off. Possibly in the case of one or two of the Author's experiments the steam was really superheated at the point of cut-off; then he thought T_1 ought to be the actual temperature at cut-off. As to the general methods of obtaining results he had nothing to object to, except on one point. The Author in his indicator diagram had adopted the method of drawing what was called a saturation curve—a curve giving the relation of the pressure and volume of steam in the cylinder during the whole period of expansion; and he had taken for his steam weight, the weight of the steam which came out of the engine and was condensed in the condenser. It was shown by his own Tables that that weight differed by 5 per cent. or 10 per cent. from the weight of the steam that went into the engine. Taking the weight of the steam admitted, the saturation curve would be higher. There was an ingenious and somewhat speculative argument in the Paper that all the leakage from the cylinders went on during the period of admission. He could not accept that, and least of all could he accept the appearance of the leakage as any guide, whether it was great or small. The appearance of a steam-leak was altogether deceptive. He supposed it was certain that the leakage continued throughout the stroke. Therefore the real saturation-curve for the weight of steam actually in the cylinder

would be a curve lying between that shown by the Author and one drawn for a greater weight of steam. In drawing the temperature entropy and dryness curves, the Author had depended on the assumption that the weight of steam in the cylinder was the weight of steam at release. If it was not so there was probably a larger error than he imagined in the position of the lines. For one thing, taking the actual steam-weight in the cylinder instead of the weight at release would enormously reduce the peaks of the curves, and considerably alter his calculations about the temperature of the steam at cut-off, if the real weight of steam in the cylinder were different from that which he took.

Professor Unwin.

Mr. S. R. CHATWOOD thought the Paper would be of the greatest value to engineers, exhibiting as it did the performance of an engine under very varied conditions of load and pressure, and with different degrees of superheat. The trials had been made with a small non-compound engine, but they were so complete that the information given would afford guidance under other conditions. It was evident that the very remarkable performance of 17·046 lbs. of steam per HP. in a small non-compound non-jacketed non-condensing engine could not be attributed to any excellence of the engine, but solely to the high superheat. Selecting from the experiments two groups of four—Nos. 28, 26, 25, 29, with saturated steam, and Nos. 35, 32, 33, 36, with steam having less than 100° superheat, and comparing the amount of heat added to the steam with the actual amount of work done per lb. of steam, the average amount of heat added in the latter group was 43·87 units, and the average extra work obtained per lb. of steam 9·42 units, representing 21·47 per cent. of the heat added as superheat. Where higher degrees of superheat were used the results were very suggestive. Thus in load series 280, p. 92, the corresponding percentages were 21·7, 52·45 and 62·47. That illustrated significantly the importance of superheating as highly as practical conditions would permit, and he ventured to think that when the matter had been developed, temperatures even higher than those which had been used in the trials mentioned would become common. The difficulties to be overcome seemed to be practical, not difficulties of principle. It was evident from the chart dealing with the temperature in the cylinder, that with the lubricants now available much higher temperatures could be reached before lubrication in the cylinder became a difficulty. The oil used in the trials had been referred to by the Author; perhaps he might be able to give some information as to the highest temperature at which that oil would satisfactorily work as a lubricant. The materials used

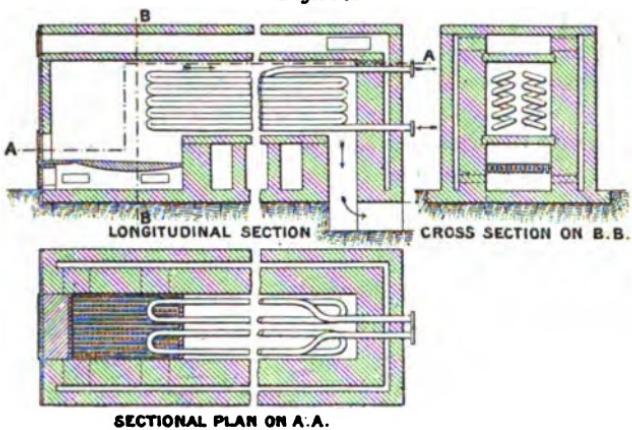
Mr. Chatwood.

Mr. Chatwood. in the construction required further investigation, particularly in respect to their properties at the temperatures in question. The practical difficulties were almost entirely confined to the superheater itself and to the conveyance of the superheated steam from it to the engine. In that respect a departure from the present practice appeared desirable. Taking the Schmidt superheater used in the trials, it would be seen that the hottest gases were used to heat the boiler, and when thus chilled, to heat the wet steam, and afterwards to superheat; whereas, if possible, the hottest gases should be used to heat the hottest part of the fluid. Probably still more open to objection were the superheaters placed in the downtake of Lancashire boilers. In the superheater trials it would be seen that the gases available for heating steam to 755° only reached the lowest coil at a temperature of 884° . That, of course, involved an enormous heating-surface. The chimney gases, leaving the apparatus at 587° , were of very large amount, as might be seen from the analysis. The whole apparatus had an efficiency of 52.8 per cent.—about as good a result as might be anticipated. It might be found practicable to combine the boiler and superheater in such a manner that the superheater might be first heated and afterwards the boiler; but at present and, he thought, in future, except perhaps in the case of very small plant, an entirely separate superheater was in every respect to be preferred. This had many advantages; the steam could be shut off from the superheater in the event of breakdown or accident, and the engine worked with saturated steam during repairs; the cost would be comparatively small, great regularity of temperature could be secured, a very high efficiency, and a perfectly independent control of pressure and temperature. He had had some experience of rough-and-ready superheaters, arranged separately from the boiler, in connection with his proposal to compress and re-heat the exhaust steam from a superheated steam-engine, to which the Author had referred. By superheating the steam an old beam-engine, of 6 feet stroke and 32 inches cylinder, had been made to run without exhaust steam and without a condenser, and also a small engine fitted with a separate compressor. He hoped that accurate data might shortly be available with regard to the economy of using steam in that manner. He would at present confine himself to pointing out that the choice lay between obtaining pressure steam by boiling water or by raising the pressure of steam by compression, and that the total heat in steam, say at 100 lbs. per square inch pressure, from hot feed-water, was twenty-five times as great as the difference in the total heat

between the exhaust steam at atmospheric pressure and steam at Mr. Chatwood. 100 lbs. pressure. It was evident that to obtain with a non-compound engine a reasonable amount of work in comparison with the size of the engine, a very high degree of superheat would have to be used; and in order to obtain some guidance as to what degree of superheat could be obtained, with a proper regard to durability and to other conditions, he had been driving works for nearly a year with steam at 800° F., and occasionally at higher temperatures. The superheater was cheaply made, and of materials which allowed it to be altered to various forms without much cost. His experience of the two forms shown in *Figs. 65* and *66* illustrated the importance of passing steam through the superheater at a very high velocity—a point on which the Author laid great stress in his Paper. The apparatus represented in *Figs. 65* had two coils passing through it backwards and forwards from end to end of a firebrick chamber, and through two pipes of 1½ inch bore about 1,000 lbs. of steam per hour was passed. When the superheater was at work, the metal of the pipes was very slightly hotter than the steam which the superheater was delivering. The way through the superheater being very small, and the steam-pipes in connection with the engine being also small, there was a considerable fall in pressure accompanied by a great fall in temperature, which was undesirable. Larger steam-pipes were inserted and the apparatus was re-arranged as in *Figs. 66*, so that there were eight pipes, constituting the way for the steam through the superheater. In that case the metal of the pipes had to be very much hotter than the steam which the superheater was delivering. The whole apparatus was much more sluggish, and responded much more slowly to an increase in firing than had been previously the case. Whilst the diagrams were intended to illustrate the importance of conveying the steam through the superheater at a high velocity, it was of equal importance to convey the steam to the engine from the superheater in large pipes at a low velocity. It appeared that at any given moment only the particles of steam in actual contact with the pipe could receive from it, or give up to it, any considerable amount of heat. The store of superheated steam thus formed was helpful by preventing the fall in pressure and temperature which would otherwise occur during the admission of steam to the cylinder. Those were rough experiments, but they illustrated some of the points which seemed essential to a durable independent superheater. In the first arrangement, *Figs. 65*, there was a high velocity of steam in the pipes in the second, *Figs. 66*,

Mr. Chatwood. a fire-brick combustion-chamber acted as a heat-regulator and prevented fluctuations of temperature, also promoting very early and complete combustion. The steam passed through the superheater in a direction opposite to the furnace gases, entering at the coldest point and leaving at the hottest, and enabling, with low-pressure steam, the chimney-gases to leave the apparatus at a temperature of 400° lower than that of the steam delivered. In *Figs. 66* the pipes nearest the furnace were sheltered from the direct contact of flame and hot gases, and were heated by radiation from the brickwork. In *Figs. 65*, the air-supply was warmed by passing through cavities in the walls, and this, combined with the free use of fire-brick, was favourable to combustion

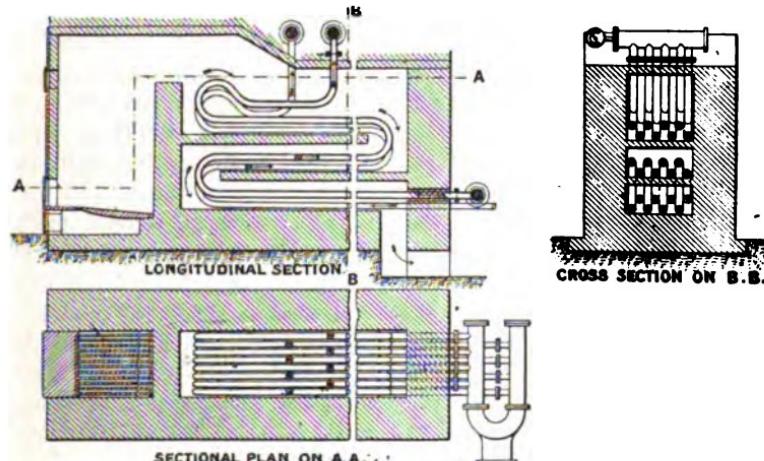
Figs. 65.

Scale, $\frac{1}{4}$ inch = 1 foot.

without excess of air. From his experience of the working of these superheaters, and from the behaviour of the pipes under various conditions, some of them destructive, he had come to the conclusion that at a temperature of 800° F. an independent superheater could be made to work satisfactorily, could be made cheaply, and would be extremely economical and durable in the hands of an average stoker. The economy might be seen in the fact that it was found possible to heat 1,000 lbs. of steam per hour with about 100 feet of heating-surface from the temperature represented by 35 lbs. per square inch pressure, to 800° F., at a cost of a little over 25 lbs. of coal. Such superheaters could be divided by partitions and have separate sets of coils for superheating the steam between the

cylinders of a compound or multi-cylinder engine. It was suggested Mr. Chatwood by the Author that there should be a greater way through the pipes for superheating the steam between the cylinders, on account of its being less dense. He thought, however, it would be found that less dense steam required to pass through the coils at a higher velocity; that was, that the necessary velocity should be measured in pounds of steam rather than in actual speed. On the general aspects of the question and the more general part of the Paper, he thought superheated steam had broken the record; but in making comparisons between it and saturated steam, it should be remembered that the saturated-steam engine, as it was

Figs. 66.



Scale, $\frac{1}{16}$ inch = 1 foot.

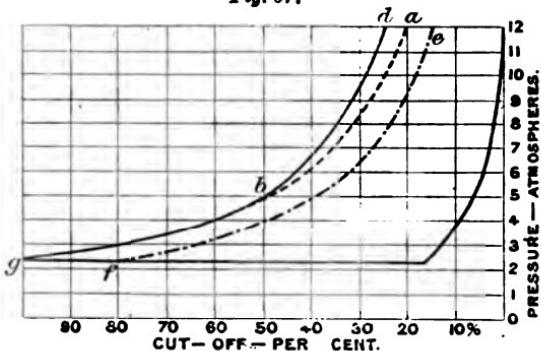
now known, was the result of a century of progress and of practice on a very extensive scale; whereas the superheated steam-engine was still in its infancy, and what it could do to-day was no measure of what it would be able to do when further developed. Nothing was more clear in the history of the steam-engine than that every addition of heat, as pressures had increased, had resulted in great economy. In superheating, the means were available of adding heat to steam at ordinary pressures, to a far greater extent than by any conceivable increase of pressure. That economy similar to that which had followed the use of high pressures would result from the further addition of heat, was not a matter of conjecture; it was shown not only by such trials

Mr. Chatwood. as those which the Author had made, and as those to which Professor Unwin had referred, but by practical experience on a somewhat extensive scale in this country some years ago, and in Alsace to-day. Record-breaking was of very little importance in comparison with economy of fuel and capital in the vast mass of steam-plant which did not approach such high efficiencies. The fact that in superheating, the heat was added without increasing the pressure, was a feature of the highest importance in its effect on the cost of engines and boilers, and rendered its use almost universally applicable. As to existing plant, superheating could be applied by independent superheaters at no great cost, with discretion as to the degree of superheating appropriate in particular cases.

Mr. Schou. Mr. PAUL SCHOU could not agree with the comparison between the Author's results and those obtained from a Willans engine showing an economy of only $7\frac{1}{2}$ per cent. in favour of the superheat. He thought the 7 per cent. clearance in the Schmidt engine would have the same effect whether working with saturated or superheated steam. It would be interesting to know whether the coal-consumption per I.H.P. shown on p. 100 was the only trial which had been made, since at a trial made abroad on a boiler of exactly the same size, the consumption of coal per I.H.P. was only 2.338 lbs., and at some later trials this consumption had been still further reduced. As to the economy which might be obtained by using superheated steam in compound condensing engines, in a recent official trial on a 100-HP. Schmidt tandem compound condensing engine, the consumption of steam per I.H.P. per hour was 9.46 lbs., and a 500-HP. Schmidt tandem compound engine now at work abroad had been guaranteed to work on a steam consumption of 8.8 lbs. per I.H.P., and in both the cases referred to only the steam in the high-pressure cylinder was superheated. There could be no doubt that if an arrangement was made to superheat the steam between the high- and low-pressure cylinders, a still further reduction of steam-consumption could be obtained. He did not agree that superheated steam at high temperatures might be safely and advantageously used on an ordinary double-acting engine, on which simply the valve gearing had been altered to suit the high temperature of the steam. It had been found that the highest temperature of the steam at which it was possible to work such an engine was 500° F. If the temperature was raised above that point, the piston-rings scored the cylinder walls. In the Schmidt engine, the temperatures varied between 660° and 720°.

It would therefore be seen that some further alteration to a double-acting engine of the present type, than simply altering the gearing, would be required to adapt it for the use of highly superheated steam. The matter was of great importance, as nearly all the engines working hitherto with highly superheated steam had been single-acting, which, of course, limited the application of superheated steam, as single-acting engines from, say, 200 HP. upwards would be too large and too expensive for any practical purpose. Hitherto the steam had been superheated to prevent the initial condensation in the cylinder, without considering that to carry the superheating out properly, the temperature of the steam should vary according to the various degrees of expansion. Hence with a late cut-off the steam was superheated more than necessary, unduly raising the temperature of the cylinder-walls ; whilst with

Fig. 67.

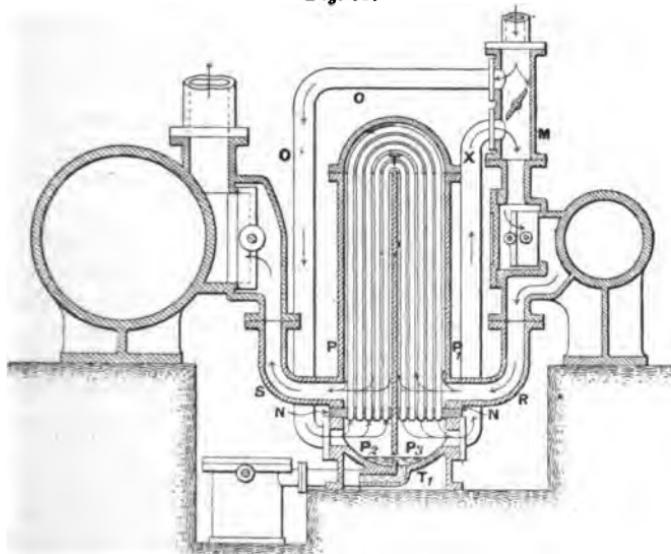


an early cut-off, the temperature of the steam was too low to prevent considerable initial condensation in the cylinder, although the degree of superheating appeared to be very high. The system, therefore, introduced by Mr. Schmidt, that the temperature of the steam at the inlet of the cylinder must be regulated so that, with any degree of expansion, the temperature of the steam must be above the saturation-point, up to, say, the middle of the stroke, was quite new. This he would illustrate by reference to Fig. 67. At the middle of the stroke, *b* marked the point of saturation ; the line *ab* was the Marriotte curve. After the steam had expanded from *d* to *b* the pressure fell, so that the increase of volume gained by superheating the steam disappeared during the period of expansion from *b* to *g*, the gain being shown by the triangle *bda*. That was on the assumption that saturated steam, by, say, 20 per cent. cut-off, expanded without initial

Mr. Schow. condensation. By reason of the initial condensation, varying with the size of the cylinder, the actual work done corresponded to an effective cut-off of, say, 15 per cent. The real work of the same quantity of saturated steam would therefore be represented by the line *ef*, so that the part which is lying outside that line represented in practice the gain by superheat shown in hatched lines. As already pointed out, there was no necessity to carry the superheat further than to the middle of the stroke, as it would be seen that the line *bg* was inclining more to the horizontal, and the amount of initial condensation would therefore be very small, and the temperature of the cylinder walls sufficiently high not to assist in the condensation. The cylinder walls would not therefore be absolutely dry, thus acting as a kind of lubricant should the oil feed-pump be out of order for a short period. In general practice, although a certain steam-consumption of the engine was spoken of for the most economical cut-off, most engines, except at the official trial, never worked with this cut-off. Sometimes an engine was ordered double the size that was required at the time when it was ordered, the result being that for a time the steam-consumption was very high. By the new method of applying the superheat this difference in economy could be made very small, as it would be possible, at the first period, to work with a high degree of superheat; and to lower the average temperature as the capacity of the engine increased. Thus for compound engines, Mr. Schmidt obtained for a large range of load almost uniform efficiency by fixing a kind of superheater in the receiver between the high- and low-pressure cylinders as shown in *Fig. 68*. The highly superheated steam entered the high-pressure cylinder through the pipe *M*, in which a throttle-valve, actuated by the governor, was fixed. Above the throttle-valve the pipe *O* branched off to the lower part, *P₂*, of the receiver, *PP₁*, which was constructed as a superheater. This receiver was, through a pipe *R*, connected to the high-pressure cylinder, and through the pipe *S* to the low-pressure cylinder. In the centre of the receiver, a division wall *T* was arranged. A series of pipes was arranged, connecting the two compartments, *P₂* and *P₃*. From *P₃* a pipe was led to the steam-space in the pipe *M* below the throttle-valve. At the bottom of the division wall a small hole *T₁* was arranged, so that the condensed water could be led out from the bottom of the two compartments *P₂* and *P₃* to an ordinary steam-trap. It would be seen that, by regulating the throttle-valve, either a full amount of superheated steam could be let into the high-pressure cylinder,

or, by closing the throttle-valve, a certain part of the highly Mr. Schou. superheated steam could be led through the receiver and be used to superheat the steam on its way to the low-pressure cylinder; this steam being afterwards led into the pipe M where it was mixed with the superheated steam from the boiler, thus lowering the temperature to suit a later cut-off in the high-pressure cylinder. It was not thought practicable by the Author to use an auxiliary feed of highly superheated steam for superheating the exhaust passing from the receiver to the high-pressure cylinder, because too large a quantity of highly superheated steam

Fig. 68.



SUPERHEATER BETWEEN HIGH- AND LOW-PRESSURE CYLINDERS OF A COMPOUND ENGINE.

would be required. This question had already been practically solved, as would be shown in *Fig. 68*, already described. The superheated steam was not mixed with the exhaust steam coming from the high-pressure cylinder, and an arrangement had been provided for, to separate, as far as practicable, the moisture contained in the steam by means of a steam-trap or similar apparatus. Should it be found in certain cases advisable not to separate the moisture in this way, the superheater could be constructed in two compartments, the lower of which would be used for drying and slightly superheating the exhaust steam

Mr. Schou, from the high-pressure cylinder, by means of the saturated steam coming direct from the boiler, the other part working in the way already described. He had found that the materials coming in contact with the highly superheated steam could withstand the high temperatures. A superheater which had been in use for the last four years at an average temperature of 720° was not showing the least sign of deterioration.

Mr. Bryan Donkin. Mr. BRYAN DONKIN thought engineers should not conclude that, because the Author had found such large economies, they would obtain in most steam-engines anything like the same effect with superheated steam. The results depended upon the particular engine. The engine used in the Author's trials was a non-jacketed twin-cylinder engine, non-condensing and running fast, but not at a high piston-speed, and it was certainly not economical with saturated steam and cold walls; but with superheated steam the results were excellent. With the two sets of walls, and the two sets of trunks in these engines heated with superheated steam, the difference of temperature between the steam and the walls was much reduced, resulting in great economy. In some cases the steam was at the same temperature as the walls, and the result was excellent. Having two cylinders instead of one, and having them single-acting instead of double-acting, the wall surfaces were increased enormously, bringing out the economy of superheating. There had been many experiments on the Continent, with large compound engines, double-cylinder and triple- and double-acting, and the economy by superheating to a fair amount in comparison with saturated steam, had been found to be between 10 per cent. and 25 per cent. according to the speed, the degree of superheating, etc. The experimental results with superheated steam with different classes of engines naturally varied widely. The more uneconomical the engine, the greater the gain by superheating; and the more economical the engine, the less the gain. It was simply a question of reducing condensation on the internal surfaces, especially on the clearance surfaces, according to the degree of superheat. With regard to the superheating tubes above the boiler, he would ask what was the material of the tubes in the Author's case, and their thickness, and particularly the rate of transmission, in thermal units per hour, per degree of difference of temperature—for the tubes, and also for the boiler surface. It should be borne in mind that the two superheaters had a total superheating surface of 175 square feet, or about four and a half times the heating-surface of the boiler proper. Probably in the boiler there would be some

priming, which would be sent on to the superheating tubes. No Mr. Bryan doubt in most cases a well-applied superheater would be more economical than an economizer or feed-water heater; both took heat from the escaping gases, in the one case heating the steam, in the other heating the feed-water. There was another interesting point brought out by the Author in his excellent and practical experiments, viz., that the greater the steam speed in the superheating tubes, the more rapidly was the heat absorbed by the steam, thus increasing the heat transmission. That he had confirmed by experiment; but there was a limit to that increase, and a maximum speed for maximum transmission. It would be interesting to know the Author's opinion, whether he had ever reached that limit, or whether he thought he could do so. He cordially agreed with the Author in the important conclusions at which he had arrived—that all the economy of superheated steam, or pure gas, was due to the higher temperature of the cylinder. This had been brought out in these experiments in a remarkable way, the superheated steam being a convenient method of raising the temperature of the internal walls, and of all the parts internally. This agreed with many of his own experiments. The superheated steam was immediately cooled and the walls heated, thus reducing or nearly equalizing the temperature of the steam and the metal; therefore much less or no condensation took place. The whole question turned on the cylinder-wall temperature in relation to the working medium, steam. The first to point out the importance of having practically dry steam at release—neither too wet nor too hot—and to make experiments on the subject, had he believed, been Professor Dwelshauvers Dery, of Liége. As to the question of lubrication, the trouble he thought had been much magnified, and with a properly selected lubricant, such as mineral oil and good metallic stuffing-boxes there need be little difficulty. In regard to the electrical thermometers, they did not appear to him to give the actual temperature of the cylinder walls, but only the temperature of the particular spot in which the thermometer was placed, viz., the clearance space. He hoped the Author would continue his electrical temperature-experiments and take the temperature of the walls themselves, which might be different from the temperature of the clearance spaces. The temperature of the clearance spaces and of the cylinder walls evidently increased with the increase of the superheat, and at the higher superheats there could not be much difference between the inside wall temperature and the steam, when the best results were

Mr. Bryan obtained without any steam condensation. The temperature of Donkin. the walls was greatly raised by superheated steam as compared with saturated steam, as he had observed in many of his own experiments. With regard to the boiler, it was a little disappointing to find such a low efficiency as 44 per cent. He thought Mr. Schmidt would be able to do much better in future. This efficiency was for the boiler alone, but taking the boiler and the superheater together it was 53 per cent. Nearly all coke fuel was used, but he did not understand why it should be used to such an extent. He believed that coal was used in Germany. Perhaps the Author would add one or two boiler experiments, using coal. The percentage of CO₂ in the analysis of the furnace gases was only about 7 per cent.—he presumed by volume, although it was not so stated. He had often obtained, with larger boilers, from 12 per cent. to 15 per cent., and even more. It would be well to try heating the air required for combustion. He observed that the temperature of the waste gases was lowered from 880° to 580°—300° F.—in passing through the superheater. It would be interesting to know the distance between the boiler and the engine cylinder along the line of pipes. He estimated the loss of temperature with superheated steam at about 1° C. per yard, and he should like to know if that agreed with the Author's experiments. According to the best authorities the temperature range in the cylinder with saturated steam should be diminished for the best economy; but the experiments described did not agree with that. The temperature range of the cylinder had been increased greatly by superheating, yet the economy was much greater. Apparently the temperature range in the cylinder with saturated or superheated steam had very little to do with the economical question. In Bavaria Professor Schröter had lately tested a large compound steam-engine, of 500 HP. He had made four separate tests with different degrees of superheat, and comparing saturated steam with superheated steam at 96° C., there was an economy of steam of 26 per cent. In this particular case, the superheat was obtained by a separately fired superheater of a different type to that described. Lately, in Germany, many tests made on Schmidt motors had been published by Professor Gutermuth.¹ The most economical results were very remarkable, viz., under 10 lbs. of steam per I.H.P. per hour. There had been several other tests giving 5 kilograms of steam per I.H.P. per hour; and the consump-

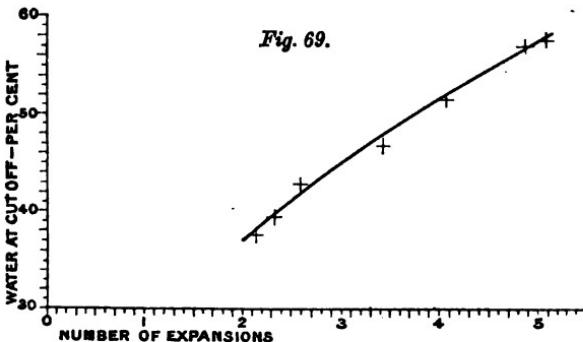
¹ Zeitschrift des Vereines deutscher Ingenieure, vol. xxxx, 1896, pp. 1390, 1419.

tion of coal was between $\frac{3}{4}$ lb. and 1 lb. per HP. per hour. He Mr. Bryan
should be glad to know if the Author thought it possible that in Donkin.
some of the rows of superheating pipes, superheated steam and water could exist together in the same pipe. He believed it was quite possible, owing to the want of circulation, or imperfect circulation, particularly in the corners. Some German experiments had also shown that the two could exist together, and that he believed was Professor Schröter's view.

Mr. M. LONGRIDGE said that the best use that could be made of Mr. Long-
such a mass of facts as had been given in the Paper was to draw a ridge.
lesson from it. But before doing this, he desired to emphasize the distinction between the savings and the absolute steam consumption shown in the experiments. The engine used for the trials was, when compared with the high-class steam-engines of the present day, a very elementary one, and the saving effected by superheating was far greater than could be expected in a first-class engine. On the other hand, the fact of such an elementary engine having attained to a consumption of 18 lbs. of steam per LHP. hour was sufficient to inspire a well-grounded confidence that, with a high-class engine, a still better result would be obtained. While on the one hand the Author's results ought not to be used to induce steam-users to believe that, by the installation of a superheater, a saving of 70 per cent. of steam would be effected, yet they did, on the other hand, afford good grounds for thinking that, with sufficient superheating and pressure, steam consumptions of 20 lbs. to 18 lbs. per LHP. per hour were within the limits of practical possibility with small non-condensing engines. When he last had the honour of speaking in that room upon the subject of superheating,¹ he dealt with two questions—"the amount of superheat required, and the means of obtaining it." To the first he gave only the general answer, that, to obtain the best results, a temperature of 600° to 650° F. would be required. He thought the Paper not only entirely confirmed the opinion he had then expressed, but it went a step further, and gave an idea of the amount of superheat required in any of the various cases to be treated, for the amount of superheat would vary in different cases. Where the clearance surfaces were large, the number of revolutions per minute small, and the ratio of expansion high, it was clear that a much higher degree of superheat would be required to keep the steam dry throughout the period of admission than where the contrary conditions prevailed. The question then was, given a

¹ Minutes of Proceedings Inst. C.E., vol. cxxii. p. 31.

Mr. Long- certain amount of water present at the end of the admission when ridge. working with saturated steam, how much superheat would be needed to keep the steam dry until the cut-off took place? This was the question he thought he might answer with the assistance of the Author's Tables. The latent heat of steam being nearly constant within limited ranges of temperature, it followed that the percentage of condensation in a cylinder, previous to cut-off, would be roughly proportional to the heat absorbed by the metal, whilst the heat given up by the superheated steam used to prevent this condensation would also be proportional to the heat absorbed, and therefore to the cylinder condensation. If then, in each of these experiments, the cylinder condensation up to cut-off with saturated steam could be found and compared with the actual amount when superheated steam was used, a fair idea would be



given of the amount of superheat required to convert any given percentage of cylinder condensation into dry steam. He had plotted in *Fig. 69* the results of those experiments, all at 6 atmospheres pressure, in which saturated steam was used; taking the number of expansions as abscissae (x), and the percentages of condensation up to cut-off as the ordinates (y). The resulting curve, the equation of which was approximately $y = 25 \cdot 6 \sqrt{n}$ showed what would have been the amount of condensation in any of the experiments had saturated instead of superheated steam been used. Taking experiment 16, for instance, the number of expansions was $2 \cdot 56$. It would be seen from the curve that the percentage of condensation with saturated steam expanded $2 \cdot 56$ times would have been 41 per cent. ($y = 25 \cdot 5 \times \sqrt{2 \cdot 56} = 41$). The actual condensation was 5.7 per cent., so that the reduction of condensation by superheating was 35.3 per cent. The amount of superheat used to accomplish

this was 253°. Dividing that by 35·3, the quotient was 7·3, or for each 1 per cent. of cylinder condensation prevented 7·3° of superheat were needed. Taking the other experiments, in which the steam was not superheated at cut-off (exclusive of Nos. 36 and 24, the results of which were abnormal), the following degrees of superheat were required to diminish the condensation before cut-off by 1 per cent.

From the 6-atmosphere trials	7·7°
" 7 " "	6·1°
" 8 " "	5·8°

The two last figures were not correct because they were calculated on the assumption that, with a given number of expansions, the condensation before cut-off would be the same with 7 atmospheres and 8 atmospheres pressure as with 6 atmospheres. Actually it would be less, and therefore the constant in the equations $y = 25·6 \sqrt{n}$ would be less. Hence the number by which the degrees of superheat would be divided would be less, and quotient greater than given above. The Author's experiments, then, seemed to show that, to obtain dry steam in an engine with 10 per cent. of water at cut-off, about 77° of superheat were necessary. If the condensation were 20 per cent., the superheat at the engine would have to be about 154°, and so on. Then, if dry steam was wanted throughout the stroke, which, in horizontal engines with heavy pistons, might not be an advantage, the Paper showed that between 50° and 100° of superheat were necessary according to the expansion and range of temperature. On the occasion referred to, he had given data from which the size of the superheater required to produce a given temperature might be determined; he had now given a rule by which the amount of superheat needed to ensure dry steam at cut-off might be estimated. Both determinations were only approximate, but he hoped they were sufficiently so to be useful.

Mr. J. G. LIVERSIDGE, R.N., remarked, with regard to the subject Mr. Liversidge. of lubrication, that trouble had arisen in Her Majesty's Navy from the oil used for cylinder lubrication appearing eventually in the boilers, where it caused loss of efficiency, and even danger. The trouble had been overcome by fitting a feed-water filter. It was placed generally on the top of the feed-tank, and consisted simply of a tank containing several thicknesses of felt, or, in some cases, bath-towelling; it was found to act very well. Very little oil was now used in the cylinders. In a large battleship, during

Mr. Liversidge. three years' commission, no oil whatever had been put into the cylinders of any of the auxiliary engines. Lubricators were originally fitted on the covers of the cylinders, but they had been removed, and bolts inserted in their places. In the new torpedo-boat destroyers running at 30 knots, with a piston-speed of 1,200 feet per minute, no means had been fitted of supplying oil, either to the steam-pipes or the cylinders, and the rubbing surfaces always appeared to be good and bright when examined. The engines were frequently opened, and kept as clean as possible, but no oil was supplied. The lubrication in these cases was no doubt supplied by the cylinder condensation, to which superheating was so antagonistic. Probably the feed-water filter, if oil was supplied to the cylinders using superheated steam, would be found useful. On page 70 the Author had shown the true effect of superheating. The theoretical efficiency was very little increased by using superheated steam. Thus, taking steam at 180 lbs. pressure, condenser pressure 1·4 lbs. per square inch, and the Clausius cycle, the available heat, without superheating, was 0·304 of the total heat expended; with 200° superheat it was 0·315 of the total heat expended. So that the increase of absolute efficiency was very small. The Carnot cycle was too high a standard of comparison, because superheating could not affect the loss due to the application of heat to the feed-water at a temperature below that of the source of heat. To prevent that loss, a feed-water heater, described by Professor Cotterill, was necessary. The Paper was interesting as showing how a very bad engine could be made into a good one by the use of superheated steam. There were many bad engines running. On board ship, for instance, there were a great many auxiliary engines, supplied with steam by an auxiliary steam-pipe which ran entirely round the ship. It was a matter of common knowledge to marine engineers that these engines were supplied with wet steam. A Paper¹ read by Chief Engineer W. H. Riley in 1893 mentioned the trials of some electric-light engines on shore, supplied by short lengths of steam-pipe, and showed that the amount of water collected at the engine end of the steam-pipe was 7·15 per cent. With a much longer steam-pipe on board ship the steam was very wet. If some means could be devised to superheat the auxiliary steam to a degree such that the auxiliary engines were supplied with dry steam, considerable gain might be obtained. It was now becoming recognized that the true function of the steam-jacket was to maintain the temperature of the cylinder

¹ Journal of the Royal United Service Institution, vol. xxxvii. p. 1080.

walls at that of the steam on admission. For if the walls had Mr. Liversidge's temperature of the steam on admission, no steam would be condensed for the purpose of heating the walls, and the walls would behave during admission as though non-conducting. On the other hand, the amount of heat supplied by the steam-jacket during expansion would have little effect on the efficiency of the cycle if condensation be prevented during admission. It would be interesting, therefore, to determine the effect of jacketing cylinders with more or less highly superheated steam, the working fluid in the cylinders being dry and saturated steam. The pressure of superheated steam increased slowly, and, consequently, the castings needed to be very little thicker and heavier, due to the superheating of the jacket-steam. Again, the superheated steam would not be in contact with the working surfaces and glands, and the difficulties of lubrication and joint-making would not be increased. Moreover, since the amount of jacket-steam had been, on the average, not more than 8 per cent. or 10 per cent. of the total consumption, the superheating plant would not be bulky, and the system could be applied to any existing jacketed cylinders.

Mr. HENRY DAVEY suggested that it would have been more Mr. Davey's useful if the results had been expressed in units of work per unit of heat, instead of in pounds of steam per I.H.P. He was afraid the Author's experiments were not convincing as to the economy of superheated steam, for his best results were no better than those obtained with engines of commerce using saturated steam; and when he considered the apparatus, and the results obtained, he was reminded of what the Duke of Wellington was reported to have said about the Perkin steam-gun, viz., that if the gun had existed before gunpowder, admiration for the invention of explosives would have been enhanced. He had not yet been able to discover why the engine used was made more or less like a gas-engine, unless it was because such high degrees of superheat might require the continuous lubrication and perhaps the water-jacket of the gas-engine. The lasting gratitude of engineers would have been earned by the Author if he had selected for his experiments, not a sort of gas-engine requiring 40 lbs. of saturated steam at 100 lbs. pressure, but a good compound engine only requiring 23 lbs. of saturated steam per I.H.P. per hour. He found, from the conclusions in the Paper, that the Author based his hopes of economy from superheating upon obtaining dry steam in the cylinder throughout the stroke, in other words, by bringing the indicator diagram up to the satura-

Mr. Davey. tion curve. He had given data¹ showing that the deficiency in that respect in good engines of commerce did not amount to more than 15 per cent. or 20 per cent., and if say 10 per cent. more heat was spent to obtain 20 per cent. more power, the gain was not so large as would be expected. That economy was to be obtained from superheating there could be no doubt, but the question for an engineer to consider was—Is the game worth the candle?—a question which, he feared, was not convincingly answered in the Paper. The Author had not been more fortunate with his boiler than he had with his engine. Giving the boiler credit for 5·7 lbs. of steam per lb. of coal, and the engine credit for 17 lbs. of steam per I.H.P. per hour, a combined result was obtained of $\frac{17}{5.7}$, about 3 lbs. of dry coal per I.H.P. per hour. An engine of commerce working with saturated steam, would use 23 lbs. of steam per I.H.P., so that with a boiler giving an efficiency of 70 per cent. instead of 53 per cent., bringing the evaporation up to 7·5 lbs., the combined result would be $\frac{23}{7.5}$, about 3 lbs. of coal per I.H.P. per hour; but he had given the Author the benefit of his best figures. By using higher pressure, saturated steam would be much more economical than the best results obtained with superheated steam, and with much less trouble and expense. The practical working of superheaters was somewhat troublesome, unless they were not superheaters, as many of them were not, and he feared that the ordinary stoker and engine man would not be so pleased with a real 650° superheater as the Author appeared to have been. Instead of such a system as that under discussion, a single cylinder engine with high superheat, it would be better to use a compound or triple engine with moderate superheat, and if the superheat could be produced in the boiler, so much the better.

Mr. Halpin. Mr. DRUITT HALPIN remarked that a good deal had been said about the boiler shown in the Paper, and about the very low efficiency of the whole apparatus. He believed it was purposely made by the inventor to work in that way. The boiler was made unnaturally small with the object of getting wet steam or a good deal of priming. The result, only 53 per cent., was remarkably low for steam produced in such a way; but it should always be borne in mind that an exceptionally bad engine had

¹ Minutes of Proceedings Inst. C.E., vol. cxxii. p. 1.

been employed, using 38 lbs. of steam; even an engine of that Mr. Halpin class could not get much lower and keep as a steam-engine. Referring to the engines of twenty-five years ago, tested at the trials¹ in Cardiff of single-cylinder engines by the Royal Agricultural Society with pressures of 80 lbs. per square inch, and similar engines of 100 lbs. at Newcastle in 1887,² it would be found that the amounts of steam and of coal were much lower than those given in the Paper. One or two references had been given by Professor Unwin, but there was another English one that might be mentioned—the remarks in Mr. Longridge's last report³ on the subject, which were exceedingly valuable and to the point. Another trial⁴ containing much information was given in the last volume of the Proceedings of the German Engineers. The engine was one of 400 HP. or 500 HP., and a collection of temperatures was given which he had never seen equalled. There was an autographic register giving the result of the gases out of the boiler into the economizer, out of the economizer into the superheater, and out of the superheater, the most complete record that could be desired. He agreed with the Author when he said that he did not believe in returning superheated steam to the boiler. There was trouble enough in getting it from the boiler to the engine without losing its superheat on the way. It might be a good method under certain circumstances when dealing with a bad boiler, priming very heavily, and where dry steam must be had at any cost, or where it would be desirable to have dry steam; but if the steam could be dried in the pipes so much the better. With regard to the brake the Author had alluded to one advantage arising from taking water into the rim—that having the temperature so absolutely under control, errors were avoided by the wheel not expanding. He thought that was true. But there was another advantage which the Author had overlooked, at any rate had not mentioned, that the possibility of keeping the temperature within low limits in the rim of the brake used gave a means of keeping the friction very constant. He had always found in running brakes, that if the temperature was not absolutely under control, the friction varied widely and the whole brake became more or less un-

¹ Journal of the Royal Agricultural Society of England. Second series. Vol. ix. p. 51.

² *Ibid*, vol. xxiii. p. 691.

³ The Engine, Boiler, and Employers' Liability Insurance Company, Limited. Chief Engineer's Report for 1895, p. 68.

⁴ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxx., 1896, pp. 1390, 1417.

Mr. Halpin. manageable. He thought the brake should have been made perfectly automatic. He should be glad to have more information as to the tube-surface of the condenser and the number of tubes. A valuable Paper had been recently read¹ on the transmission of heat through metals, and the data which he had mentioned would be exceptionally valuable, as then the actual transmissions under the circumstances at the different velocities of water used in the condenser could be derived. He imagined the whole of the steam in any one experiment was condensed, that none of it escaped as vapour, and also that the whole of the superheat had disappeared at exhaust; but the figures the Author had given as to the condensing water per pound of steam, and the rise in the temperature of that water, varied enormously. In experiment 12 the thermal units carried off were 856, and in experiment 35 they were 1,025. In number 4, which appeared to have the highest superheating (357°), the thermal units were 908.

Professor Ripper. Professor RIPPER, in reply, expressed his indebtedness for the kind way in which his Paper had been received. The weight of water that passed through the condenser had been corrected for temperature, because the circulating water was measured, not weighed, and the measuring tanks, having a graduated scale, the reading by the scale required to be corrected for temperature. He thought enough had been said to make it clear that the number of cases in which steam was superheated at cut-off was more numerous than inferred by Professor Unwin. The mean temperature registered in the clearance space, was—when the load was high and the superheat high—above the saturation temperature of the initial steam, showing that if the walls were above the temperature of the saturated steam, the steam at cut-off must have been superheated, Fig. 63, Plate 3. He might further say that in the trials which had been conducted in Germany by two eminent experimenters, the indicator diagrams of the high-pressure cylinder, using the same degrees of superheat as were used in these trials, gave almost identically the same result, showing the steam dry at release, and considerably superheated at cut-off. A question had been raised with regard to the position of the saturated-steam line on the diagram, and it was urged as almost certain that some steam did escape from the piston between the cut-off and the end of the stroke. Now, if the steam as shown by the saturation curve, and calculated from the weighed exhaust, was not correct

¹ Proceedings of the Institution of Mechanical Engineers, 1896, p. 134.

in consequence of some of the steam having escaped through the piston during expansion, the true weight of the steam in the cylinder would be greater than that actually taken, which would cause the saturation line to be removed a little further to the right in the figure, making the steam a little wetter where it was not superheated, and a little less superheated where it was superheated. On the other hand, if some of the steam escaped from the piston valve, which was even more likely than that it should escape from the piston, then there had been more steam weighed in the weighed exhaust than actually passed through the cylinder, the effect of which would be that the saturation line would have to come back towards the left of the figure. The quantities involved were very small, and their respective effects on the position of the saturation curve were exactly opposite; he thought it reasonable to conclude that they neutralized each other. He therefore considered that the saturation curve was correctly placed, and that the temperature calculations were accurate. He did not think that "mean temperature" would be misunderstood, as suggested by Professor Unwin; besides, if it were, the error would be extremely small within ordinary ranges of temperature. It was scarcely justifiable to speak of his experimental engine as "a very bad one." It was never intended for saturated steam, although even so used it compared well with a Westinghouse engine of like size and horse-power.¹ Commercially the Schmidt engine was proving very successful, and at the same time showing phenomenal results in the matter of steam consumption. The Paper, however, was intended to show the value of superheating, without regard to the merits of the engines. He should be glad, indeed, to have the opportunity of conducting an experiment with a compound-engine. As to the quality of the oil, Messrs. Boult, who provided the valvoline used in the trials, had furnished the following report, by Mr. G. Watson Gray, F.I.C., who examined the oil by fractional distillation:—"At 600° F., 1·5 per cent. over; at 766°, 10 per cent. over; at 779°, 20 per cent. over; at 795°, 50 per cent. over; at 799°, 70 per cent. over. The remaining 30 per cent. was as fluid as the original oil, and free from any deposited solid matter." He had had some experience with a double-acting engine 50 I.H.P., working regularly with steam superheated to 650° F. or 700° F. The engine had piston-valves and metallic packing in the piston-rod and valve-rod glands, but in other respects there was nothing special about its

¹ Minutes of Proceedings Inst. C.E., vol. lxxix. p. 86.

Professor construction, yet it worked perfectly and gave no trouble of any kind. He thought there must be some error in the statement of a steam consumption of 8·8 lbs. per I.H.P. per hour, as this was within 4 per cent. or 5 per cent. of the theoretical limit, and left little margin for losses by radiation, leakage, and condensation in the low-pressure cylinder. He considered Mr. Schmidt's arrangement for reducing the temperature of the superheated steam in the cylinder of double-acting engines, when the cut-off was late, by introducing a supplementary supply of saturated steam, very ingenious. It was evidently designed to prevent the possibility of any risk through excessive superheating, but on the whole he thought it would be preferable to regulate the temperature of the superheated steam by regulating the heat-supply to the superheater; and separate, independently fired, superheaters would lend themselves best to such regulation. The separate fires for superheaters would usually be small, and if made thick and with a small grate-surface, it would not be difficult to regulate the supply of heat by adjustment of the draught. It would then not be necessary first to heat the steam and then to cool it before it reached the cylinder. He could not agree with Mr. Schou's statement that the quadruple-expansion engine, "even working at 25 atmospheres, would show no advantage whatever over the two-cylinder compound;" on the contrary, he thought that with each step taken in increasing initial pressure, a further increase of efficiency would result, and the tendency appeared to be in the direction of considerably increased pressures combined with high superheats. It was difficult to say from which source the greater gain was to be expected, increased pressures or superheating; but there could be no doubt about the result of their combined effects. The temperature of saturated steam at 1,000 lbs. pressure per square inch was only 546° F.; so there was room, even at such high pressures, to benefit by the use of superheated steam, and still to keep within practical limits of temperature. With saturated steam Mr. Donkin had shown that the greater the range of temperature between the initial and back pressures the greater the loss by cylinder condensation, because the difference between the mean temperature of the cylinder walls and the initial temperature of the steam increased with the range. The mean temperature of the walls could be raised by increasing the weight of the steam passing per stroke, or by increasing the speed, or by superheating. When the increased range was due to superheating, the superheat raised the mean temperature of the walls up to, and in some cases beyond, the temperature of saturated

steam at initial pressure. As to the existence of water in the presence of superheated steam, he saw no difficulty in supposing that water in the form of globules, in the process of being evaporated, might be swept forward through the lower coils, and exist for a short period in the presence of superheated steam. This seemed to be proved by the fact that a considerable fall of temperature took place in the vertical chamber connecting the second coil from the bottom with the top coil of the superheater, though the steam entering this chamber was highly superheated. The fall of temperature was probably due to the evaporation of water carried over with the superheated steam into the chamber. The length of steam-pipe between the superheater and the engine stop-valve was 48 feet. The area of the tube surface of the condenser was 46 square feet. He agreed with Mr. Davey that the number of units of work per unit of heat was a useful measure of efficiency. It was only another form of "absolute thermal efficiency," the value of which was given for all the trials and from which the form suggested by Mr. Davey might be at once obtained thus: units of work per unit of heat = $778 \times$ absolute thermal efficiency per cent. $\div 100$.

Correspondence.

Mr. WILLIAM FAIRLEY thought the Paper gave abundant proof of Mr. Fairley, the accurate and exhaustive manner in which the trials of the engine in question had been carried out. At the same time, it was a pity the labour expended on the trials of the small Schmidt motor had not been devoted to a plant more in accordance with usual English practice. The boiler, superheater and motor must be considered as a whole, and no element of economy in the use of steam in the cylinders should be considered, without also taking into account the want of economy in the steam-generator. The plant having been built for the special purpose of generating and utilizing superheated steam, the trials with saturated steam might have been omitted, as the motor was of a type not suitable for the economical use of saturated steam, and consequently a comparison of the results obtained with superheated against saturated steam was unfair. From the point of view of the steam-user, whose chief object was the production of power economically, it would appear that the generator, motor, &c., in question, even with a very high degree of superheat, were not more economical than many engines and boilers constructed in England of similar power, using

Mr. Fairley, saturated steam only. The trials no doubt proved the proportionate gain in economy (so far as quantity of steam used in the cylinder was concerned) as the quantity of heat carried in by the steam was increased. At the same time numerous trials, proving this point, had already been made on the Continent, the majority carried out with engines larger and more perfect in construction than that referred to in the Paper. It was almost generally agreed that large economy might result from the judicious use of superheated steam, but if it was to be more generally used, the apparatus for its production must be suitable for connecting to existing plants, with the present types of boilers and engines.

He had, during the past two years in the pumping-station of the Richmond Main Drainage Board, used superheated-steam in some eighteen sets of engines of various types, and would point out one or two of the practical difficulties which he had observed. The superheater was of the Schwoerer type, the castings having been supplied by Messrs. J. Simpson and Company. It was placed at the back of a Galloway boiler, where the temperature was high, as the gases issued from the boiler flue. No difficulties had been experienced in the regulation, within certain practicable limits, of the superheater, nor in any of the different types of engines in use had serious practical difficulties arisen from the use of superheated steam in the cylinders, although no attempt had been made to obtain such high temperatures as those obtained by the Author. The chief difficulty that had to be contended with, was one which would be experienced in any large work having a considerable length of steam-pipe in daily use, namely, the conveying of the superheated steam from the superheater through the steam-pipes without losing almost the whole of the added heat before the steam reached the engines. As to the regulation of the superheater, the Author's experience was similar to his own, although he had not found the apparatus quite so sensitive to the draught of steam as the Author had apparently found his plant. If the steam, however, was taken into a range of steam-pipes and used in the ordinary way it would be found in working that, although there was a considerable gain in using the steam in the condition in which it reached the engine, yet the amount of superheat was unappreciable, and it would appear that, not only must the steam move at a high velocity through the tubes of the superheating apparatus, but it must also be carried along the steam-pipes at a high velocity to the point where it was to be used. Numerous experiments had been made on this point, and in one case he had found a higher degree of superheat could

be taken through 150 feet of steam-pipe, in a case where the Mr. Fairley. steam-piping was too small to convey saturated steam to the engines, than was obtained in an engine within 50 feet of the superheater, and where the steam was moving at about the same velocity as if saturated steam had been used, the pipes being of sufficiently large diameter for all purposes. With reference to the leakage round the pistons, the Author appeared to hold the view that it was smaller with superheated than with saturated steam. This was contrary to his experience. He thought the waste with superheated steam from a leaky joint would be found much more serious than with saturated steam. Steam-piping, steam-chest covers and pistons, which to all appearances were steamtight when used with saturated steam, developed a considerable amount of leakage when superheated steam was used.

There was one class of engine in which it would appear superheated steam could, in a great many cases, be used with considerable advantage. He referred to the ordinary type of duplex-pump, which was much in favour, and was used in many cases on account of convenient form and handiness, without reference to its wastefulness of steam. In such an engine he had found that with a moderate degree of superheat in the cylinders, an economy varying between 20 per cent. and 30 per cent. could be effected. With the better class of engine the economy was proportionately smaller. He believed the use of superheated steam would yet become more general when the economy arising from its use was more fully known; but he thought a superheater placed in a separate, independently-fired furnace, and not, as generally attempted, in the boiler flues, would be found more convenient and not much less economical.

Mr. R. A. HADFIELD asked, with reference to the important Mr. Hadfield. question raised in the Paper regarding the heat exchange between the steam and cylinder walls, if any definite information was available as to the value of different classes of material for this purpose. He understood considerable economy had been obtained in America by lining the cylinder-walls with a non-conducting material, and by constructing the cylinders of a material of low conductivity. It would no doubt be possible to produce alloys having much lower conductivity than the ordinary material now used, and, perhaps, the Author would say if he had any knowledge of such results. This Paper had dealt with an important development which English power-users would do well to investigate, and it was another proof that the technical schools should in the future prove of the greatest service in

Mr. Hadfield, calling attention to important developments which it was impossible for the ordinary manufacturer to work out amidst the ordinary high pressure of business routine.

Mr. Patchell. Mr. WILLIAM H. PATCHELL thought the question of primary importance was how to increase the economy of existing steam plants. The arrangement of superheaters shown in the Paper formed an effective application of the counter-current principle; he believed it was usual to add a water-heater in the manner suggested by the Author. Regulation of the amount of heat was the crux in superheating; with a grate-area of 2 square feet and a steady load the Author had found no trouble, but during periods of cleaning fires and varying loads, with a boiler evaporating say 10,000 lbs., or 12,000 lbs. of water per hour, such smooth running would probably not be obtained with the arrangement shown. He had frequently combated the error to which the Author had drawn attention of rating the superheating surface as boiler heating-surface. The superheating tubes could not be credited with evaporation unless there was water to evaporate, and if the superheating surface was rated as evaporating surface, it condemned the boiler as a priming one. Superheat might be used in many ways; it could be carried through to the engine as in the Author's trials, or it might be used to counteract the condensation in long steam-pipe ranges, or to increase the boiler-power; or, as he had found, these two latter alternatives might be combined with great advantage by the use of the McPhail-Simpson apparatus. If it was this apparatus to which the Author had referred as a "so-called superheater," it would be interesting to know why this epithet had been used. He had seen many tests on the apparatus, but never one in which it failed to superheat the steam as judged by the Author's definition, p. 61. The degree of superheat was predetermined by the dimensions of the pipes used, and varied in different apparatus. He had tests before him showing regulated superheats up to 240° F. above the normal temperature. Exception might be taken to the indicator springs being calibrated cold. The mechanical efficiency of the Schmidt engines must undoubtedly be of a high order, for similar results to those recorded by the Author had also been obtained by Professor Schröter in the summer of 1894 on a Schmidt single-crank vertical tandem engine indicating 70 HP. On the first day's running this engine had given 86·5 per cent. mechanical efficiency, and on the second day 82·6 per cent., being a mean of 84·5 per cent. Temperatures of 600° F. might be arranged for without much difficulty in isolated plants, but he viewed with apprehension such tem-

peratures on long ranges of steam-pipes and connections as obtained Mr. Patchell. in central-station plants unless it was steady, as the changes in temperature would fatigue the materials and lead to considerable trouble with the joints. As to the deterioration at these temperatures, he had not had the slightest trouble or found any signs of deterioration in superheating pipes after three and a half years' work day and night. He did not consider the Author's 2 square feet of grate-area sufficient premises from which to draw his conclusions for the safe and economical use of these high amounts of superheat. They might be, and in fact were, economical on the plant described, which was very poor without them; but he thought true economy in most cases, where fairly economical engines and boilers were already at work, would be rather on the lines of moderate degrees of steadily-regulated superheat, which was now easily obtainable without danger or inconvenience and brought a gain of 15 per cent. to 25 per cent.

Mr. W. SCHMIDT, of Aschersleben, Magdeburg, remarked that in Mr. Schmidt. November, 1896, trials had been made at Nuremberg of a 100-HP. tandem compound Schmidt motor by the Bayrischen Dampfkessel-revisions Verein. They had extended over four ordinary working days of eight hours, during which the engine was working at the rate of 105 I.H.P., that was to say, at an uneconomical rate of expansion. The consumption of steam, however, had not exceeded 9.46 lbs. per I.H.P. per hour, while a consumption of only 10.56 lbs. had been guaranteed. The plant included two vertical transverse tubular boilers, with superheaters, fired with Westphalia coal, the rate of evaporation being 7 and the feed-water temperature only 11° C. During 1896 a superheated steam-engine of 500 HP. to 650 HP. had been installed at the Thale Ironworks, and had since been working day and night. It drove a plate-rolling plant, and was therefore subjected to unusual variations of load; it had nevertheless from the first worked with perfect regularity. More than one hundred superheated-steam engines had been put to work, and all had satisfied the highest expectations with regard to economy.

Mr. M. SCHROETER, of Munich, observed that at the time of his Mr. Schroeter. trials at Cassel, referred to by the Author, the feed-water consumption of the 60-HP. compound engine of the Schmidt type, built by Messrs. Beck and Henkel, was the lowest ever recorded by any steam-engine, viz., 12.2 lbs. per brake HP. per hour. It had since been surpassed by a 100-HP. compound engine, built by Messrs. Dingler at Zweibrucken and tested by Professor Guter-muth, who obtained 11.5 lbs. steam per brake HP. per hour

Mr. Schroeter, with the same steam-pressure and superheating temperature (350° C.). A larger engine had given still better results; and feed-water consumptions of 10·29 lbs. per I.H.P. per hour had been obtained¹ with an 800-H.P. Corliss engine of the ordinary double-acting-type, built by Messrs. Berger André at Thann, and similar numbers for other engines.

The feed-water consumption would, no doubt, be brought down to 10 lbs. per brake HP., or 9 lbs. per I.H.P. with large engines, and a temperature of the steam of 350° C., and his own experience led to the same conclusion at which the Author arrived, that in the use of highly superheated steam lay the means by which the theoretical limits of the steam consumption fixed by the well-known thermodynamic formulas might be approached, if not reached. The number of superheating plants was daily increasing in Germany. Of the Schwoerer type of superheater there were now running more than eight hundred plants, combined with boilers of every description and pressures up to 20 atmospheres. Seven hundred of these were producing about 120,000 HP., and about 200,000 HP. were now produced by superheated steam. The economy over saturated steam was considerable, but in some cases the resultant gain was much smaller, all things being considered, and this influenced the cost of the effective HP. Not only the coal burnt for superheating, but also the excess of oil required and the interest on the capital must be taken account of, for as the Author justly observed: "It is not the steam that does the work, but the heat." It was thus of the greatest importance to have as high an efficiency as possible for the boiler and superheater taken together, otherwise the economy in coal might be far less than the economy in steam. As to the causes of the latter the Author had added a new proof of the usefulness of the temperature-entropy diagram. He could corroborate the statement that the practical difficulties, formerly so dreaded, had almost entirely disappeared, even large double-acting engines of the ordinary type were working quite satisfactorily with high degrees of superheating.

Concerning the use of superheated steam in the low-pressure cylinders of compound engines, he might quote an experiment² made by Prof. Gutermuth, with the 100-H.P. engine referred to. Superheating the steam in the receiver from 173° C. to 244° C. was found to lower the steam-consumption from 4·806 kilograms

¹ "Report of the Association Alsacienne de Propriétaires d'Appareils à Vapeur" of 1896.

² Zeitschrift des Vereins deutscher Ingenieure, vol. xxxx, 1896, pp. 1390, 1417.

per I.H.P. to 4.736 kilograms, but at the same time the coal consumed increased from 0.766 kilogram to 0.808 kilogram per I.H.P. This result could not be generalized. In this special case a second boiler was used for the intermediate superheating, and so the unfavourable result might easily be explained. It was interesting to note that even a superheating of 111° C. above the temperature of saturation was not sufficient to hinder the condensation on the walls of the low-pressure cylinder.

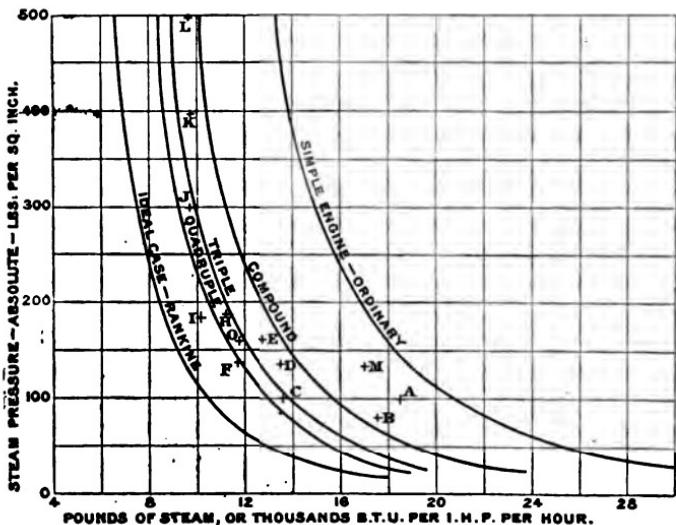
Professor FRANCESCO SINIGAGLIA, of Naples, observed that the importance of superheating had long been undisputed, even before Hirn had found, in his celebrated experiments, economies of 20 per cent., 31 per cent., and 47 per cent. with steam superheated 210° C., 225° C., and 245° C. respectively. The trials described in the Paper showed the application of steam superheated 163° C., by the method of mixture which was the best for regulating the amount of superheat. The system had hitherto not been applied on so large a scale as was to be expected, but, like all industrial problems, it was complex, and its final result ought to be counted by the saving effected, having regard to the cost of installation, the repairs, the idle time, etc. It was only by an active propaganda that the benefits of the application of scientific truth were to be shown in practice. To popularize, then, the methods of the laboratory and the results of well-conducted experiments was a means of contributing to the progress of the steam-engine. The experimental work of the Author was, on this account, very important. His engine, however, possessed extraordinary features. The advantage of superheat, which was now regarded as the most efficient method of improving the economy of the steam-engine, was clearly shown in the Paper, the entropy diagram threw theoretical light upon the questions, and the heat-exchange diagrams, after Prof. Dwelshauvers-Dery, limited by the Author to the period of admission of the steam, showed the influence of the cylinder-walls at different degrees of superheat. The Paper was of great theoretical and practical importance, and dealt with many details useful to engineers.

Professor R. H. THURSTON had read the Paper with unusual interest, as he had but recently had occasion to look into the whole subject of superheating, and to collate the evidence bearing upon this important and growing question.¹ His con-

¹ "Superheated Steam: Facts, Data and Principles relating to the Problem." By R. H. Thurston, Transactions of the American Society of Mechanical Engineers, vol. xvii. p. 488.

Professor clusions were substantially those expressed by the Author in the Thurston introduction to the Paper. Among all the records of engine-trials in which the effect of superheating the steam was exhibited—and there were many—he had found none as complete and as satisfactory in its detailed illustration of the method and the result of this system of increasing efficiency, as that given in the Paper. In no case had superheating been carried to such extent in regular working as in the Schmidt engine, so that it was well suited for illustration and measurement of the value of the process. On the other hand, so small an engine was subject to great "cylinder-

Fig. 70.



A, Sulzer, 1; B, Corliss, 1; C, Sulzer, 2; D, Sibley College, 3; E, Rockwood, 2; F, Reynolds, 3
G, Sulzer, 3; H, Leavitt, 3; I, Schmidt, 2; J, K and L, Sibley College, 4; M, Schmidt, 1.

STEAM-ENGINE EFFICIENCIES.

condensation," and thus excessive superheating was demanded to extinguish that form of heat-exchange. This, in turn, prevented the full value of the process being realized as in a larger engine; it required 350° of superheat to insure complete suppression of initial condensation. He considered 100° of superheat, in ordinary large mill-engines, would reduce this waste to nearly a minimum. This was also why, even with 326° of superheat, and with steam at more than 130 lbs. per square inch pressure, the steam demanded amounted to 17 lbs. per I.H.P. per hour—50 per

cent. more than the best present record. The results reported¹ Professor Thurston. for an earlier engine of the Schmidt type formed a better example. The best results with saturated or nearly saturated steam hitherto obtained, and those of Professor Unwin for another Schmidt engine, were compared in *Fig. 70* with the ideal and proportional efficiencies computed by now familiar processes.² The ordinates represented absolute pressures, and the abscissas lbs. of steam per I.H.P. per hour and equivalent heat, assuming that, with return of jacket-water in usual proportions, the steam received, at the boiler, 1,000 B.T.U. per lb. In many cases, however, this figure was more nearly 1,100 B.T.U. The curves showed the performances of well-known engines using ordinary steam. That marked H, was Leavitt's Chestnut Hill pumping-engine; I, was the case of the larger Schmidt engine reported by Professor Unwin; J, K, L were figures obtained from the 20-H.P. four-cylinder experimental engine of Sibley College at various pressures up to 500 lbs. per square inch. Were this latter engine reproduced on a large scale, it would carry its figures over beyond the line designated as that which should be reached by good quadruple-expansion engines. The base-curve was marked "ideal," and represented the work of the ideal engine with saturated steam, worked in a non-conducting cylinder, and in the Rankine cycle. The parallel curves were those for multiple-cylinder engines, assuming the internal waste inversely as the number of cylinders in series. The figures attached to each name indicated the number of cylinders in series. One Sibley College engine was rated at 20 I.H.P. at 500 lbs. pressure. The other was rated at 175 HP. at 175 lbs. pressure; but it has only been worked as yet at 100 lbs. or 125 lbs. He had inserted at M the point indicating the relative standing of the engine which was the subject of the Paper. He had found that increased speed of rotation of a shaft might improve lubrication by promoting the supply of the lubricant sufficiently to sensibly reduce the friction-waste of the machine. He thought, however, there was a limit to this particular effect; the friction of fluid becoming after a time sensible, increasing, as it did, as the square of the velocity of rubbing. Similar results to those summarized in his own conclusions had been obtained by Mr. Dixwell in his Massachusetts Institute of Technology investigation at Boston twenty years ago.³ It was interesting to find such complete accord

¹ Professor W. C. Unwin, Minutes of Proceedings Inst. C.E., vol. cxxii. p. 179.

² "Manual of the Steam-Engine," vol. i. New York: J. Wiley and Sons.

³ Transactions of the Society of Arts, Boston, 1875.

Professor Thurston. with these later researches and more scientifically complete investigations. In the Paper¹ referred to he had stated the conclusions to which he had been led by the results of his research. The present value and the future potentialities of superheating could not be now disputed. A good and durable superheater, capable of giving the degree of superheat required at any stated cut-off, and adaptable to any size of engine, in such manner as to just extinguish the condensation due to the heat-exchange between the entering steam and the cylinder-wall, was the one thing necessary in the improvement of the existing machine with metal cylinder-wall.

Professor Ripper. Professor RIPPER, in reply to the Correspondence, observed that the difficulty felt by Mr. Fairley, and by many other engineers, was that of conveying the superheated steam from the superheater in long ranges of steam-pipes without losing almost the whole of the added heat before the steam reached the engines. On the other hand, Mr. Patchell asked why an arrangement should be spoken of as a "so-called superheater" which first superheated the steam and then deliberately turned it into pipes standing in the comparatively cold water-space at the bottom of the boiler in order to cool it; after which it superheated it again, and again turned it into the water-space of the boiler to again cool it. After this treatment it was sent forward to the engine. It might be contended that there was no loss of heat by this arrangement, because the heat lost by the steam was used to evaporate water. That was so, and to that extent the "superheater" was not really a superheater, but an extension of boiler heating-surface, as was all surface which transferred heat, directly or indirectly from the furnace gases to evaporate water as distinguished from superheating the steam. This accounted, he thought, for the increased power, and perhaps also for the increased efficiency of boilers fitted with this device. He considered the best remedy for the difficulty pointed out by Mr. Fairley was to supply saturated steam at the boilers, and to fix separately-fired superheaters as close as possible to the respective engines. The experience of Mr. Fairley that the steam must move at a high velocity, not only in the superheater but also between the superheater and the engine, appeared to be different from that of Mr. Chatwood, who had maintained that while high velocity in the superheater tubes assisted the flow of heat to the steam, velocity

¹ "Superheated Steam: Facts, Data and Principles relating to the Problem," loc. cit.

would have an opposite effect, and accelerate the rate of cooling after the steam had left the superheater. With reference to Mr. Hadfield's question as to the value of material of low conductivity for cylinder walls, Professor Thurston had recorded several experiments¹ as to the effect of coating the cylinder covers and ports and piston faces with non-conducting substances; and Dr. Kennedy had used sheet-lead linings for the same purpose. But although advantage had been found to result therefrom, the use of such substances had never passed beyond the experimental stage. If such a metal could be found, as was suggested by Mr. Hadfield, the present loss by cylinder condensation in ordinary engines might be much reduced, though the effect of the material of the walls would be modified by the presence of moisture and oil in the cylinder.

19 January, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President,
in the Chair.

The discussion upon the Paper "Superheated Steam-Engine Trials," by Professor W. Ripper, was continued and concluded.

¹ "Superheated Steam: Facts, Data and Principles relating to the Problem," p. 488.

26 January, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President,
in the Chair.

(*Paper No. 2984.*)

"The Diversion of the Periyar."

By JOHN PENNYCUICK, C.S.I., Col. R.E.

FROM time immemorial the district of Madura has suffered from the want of water for irrigation. With the exception of a small area at its south-western extremity, its geographical position prevents its receiving more than a scanty supply of rainfall. Almost all of this is utilized, either by means of storage in tanks or by channels leading from the Vaigai river, which drains the greater part of the district and receives the surplus from these tanks when filled. So thoroughly is the available rainfall utilized that it is only on very exceptional occasions, not more than once or twice in an average year, and in many years not at all, that any water is carried by the Vaigai to the sea.

In marked contrast to these conditions are those of the Travancore territory on the other side of the mountain chain which divides the watershed of the Arabian Sea from that of the Bay of Bengal. Here the yearly rainfall is between 80 inches and 150 inches, giving perennial rivers, and a land of perpetual verdure. The Periyar river, which drains the portion of Travancore adjoining the south-west corner of Madura, flows for some distance within a few miles of the watershed ridge, its bed being less than 200 feet below the lowest openings in that ridge. It is not surprising that for many years a desire should have been felt to divert a portion of the superabundant supply of this river into the valley of the Vaigai for the benefit of the Madura district. The idea of thus diverting the waters of the Periyar is probably very ancient; but the first recorded expression of it dates from the beginning of the present century, when surveys were made for the purpose of ascertaining how far the proposal was a practical one. The result of these surveys, which appear to have

been made in a somewhat half-hearted manner, was to condemn the idea as impracticable; and, although it was repeatedly brought forward, it was not till sixty years later that the question was taken up in earnest by the late Major Ryves, R.E., who submitted the outline of a scheme sufficiently promising to justify the Government of that day in ordering it to be worked out in greater detail.

The conduct of the necessary investigations was entrusted to the Author, and the result was the submission to Government of a tolerably complete scheme for the diversion of the river. An essential feature of this scheme was the closing of the existing river channel by an earthen dam about 200 feet high, it being supposed that the cost of a masonry dam would be so great as to be prohibitory. The Government, rightly in the Author's opinion, considered that the risk of failure in an earthen dam of a height so greatly exceeding anything previously attempted was too great, and declined to sanction the scheme. The investigations already made served, however, to show so clearly the enormous advantage to the Madura district which would accrue from the diversion of the Periyar, that the subject was not allowed to drop; and when the Author a few years later brought forward a proposal for the substitution of a masonry dam for the earthen bank formerly proposed, the suggestion was accepted. After much discussion, a complete scheme both for the diversion of the river and for the distribution of the water thus obtained, was sanctioned for execution and the necessary funds were provided.

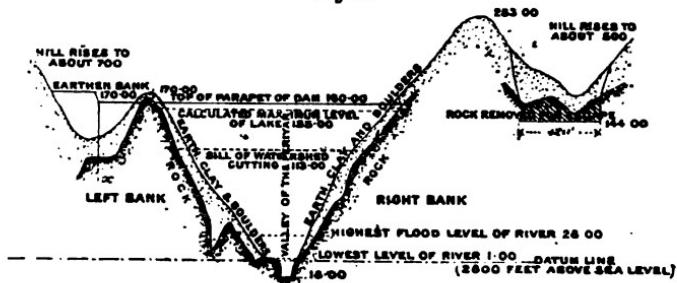
The problems to be solved were:—first, the closure of the existing river-bed by a solid masonry dam; second, the provision, either by an open cutting or a tunnel, of means for the passage of the waters of the river through the mountain ridge separating the valley of the Vaigai from that of the Periyar; and, third, the construction of the works necessary for the distribution of the water thus obtained (amounting to some 30,000 million cubic feet annually) for irrigation in the Madura district.

It had originally been intended to make the relative levels of the dam and cutting, or tunnel, such as merely to divert the course of the river, without any provision for storage of water. But the later investigations had shown that this would not be enough, and that sufficient water must be stored between the sill of the cutting and that of the weir by which surplus water was passed back into the Periyar valley, to overcome the fluctuations in the natural discharge of the river, and to allow a constant supply to be passed, under complete control, into the Madura district. The storage necessary for this purpose was calculated

to be about 7,000 million cubic feet; and subject to this condition, the relative levels of the escape weir and of the sill of the cutting or tunnel, would be fixed by considerations of convenience and economy. It was ultimately decided that the crest of the escape should be 144 feet above the datum of the Periyar surveys, at that time supposed to represent the mean level of the river-bed at the site of the dam, the crest of the dam being 11 feet above this with a parapet 5 feet higher. It was calculated that, with the length of weir available, the maximum depth of water passing over it would be 9 feet.

The passage of the water through the watershed ridge was designed to be effected by a cutting 21 feet wide with a slope of 1 in 440, leading to a tunnel with a cross-sectional area of 90 square feet and a slope of 1 in 75. The length of the cutting was calculated

Fig. 1.



Horizontal scale, 1 inch = 1,000 feet; vertical scale, 1 inch = 200 feet.

LONGITUDINAL SECTION ALONG DAM AND ESCAPE.

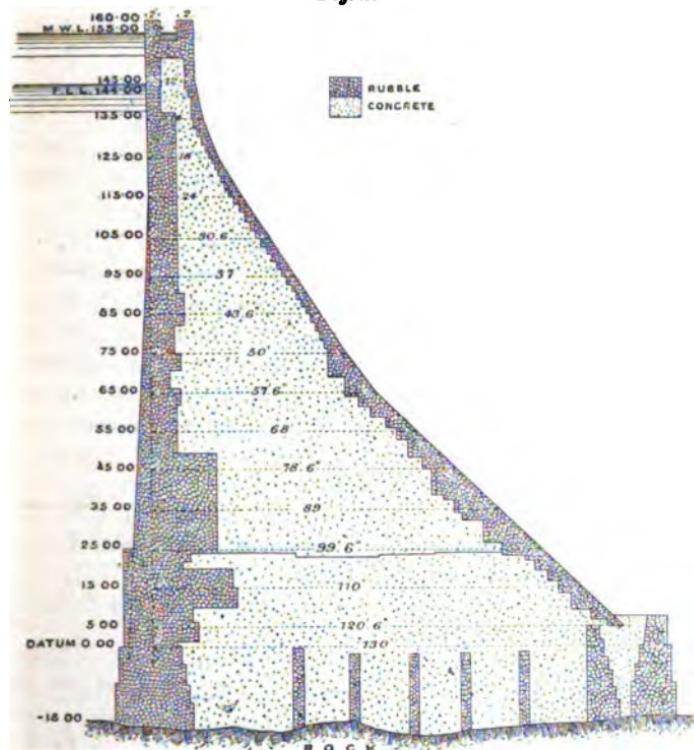
at 5,400 feet, and that of the tunnel at 6,600 feet, a length which was considerably reduced in execution by a change in alignment. The sill of the cutting, at its starting-point, was 113 feet above datum; the content of the lake between this level and that of the escape weir was calculated at 6,815 million cubic feet; that of the lake below the former level (which would of course not be available for irrigation) being 6,484 million cubic feet.

The valley at the site of the dam has a width of about 200 feet at datum level, and 1,300 feet at the level of the top of the dam. On each bank was a short saddle, formed by a depression between the hills immediately flanking the river, and a higher range farther from it. It was proposed to use both these saddles as escapes, that on the right bank being cut down, and that on the left, which was considerably lower, being built up to the required level of 144 feet. A section transverse to the valley and

longitudinal to the dam and escapes is shown in *Fig. 1*. The section to be adopted for the dam was the subject of considerable discussion, in which the Author took a prominent part. The section ultimately adopted was that shown in *Fig. 2*.

It was proposed to construct the dam entirely of concrete, the stone for which was to be obtained partly from the waste-weir on

Fig. 2.



Scale, 1 inch = 50 feet.

CROSS SECTION OF THE PERIYAR DAM.

the right bank, and partly from the water-shed cutting. These intentions were slightly modified in execution, as it was found that the number of masons available was much larger than had been expected, and about one-third of the total content of the dam was built of rubble. Difficulties of transport prevented more than a very small quantity of the stone from the cutting from being used, and separate quarries were opened for the supply of so much

of the stone as could not be obtained from the waste-weir—about a third of the whole.

In order to construct the foundations of the main dam, it was proposed by the Author to use temporary dams across the river, above and below, and by their means to divert the water into a tunnel driven through the solid rock on each flank. One of these (on the right bank) was also to be used for the supply of water to a turbine which would drive the greater part of the machinery required for stone-breaking, concrete-mixing, and other purposes. Either from an imperfect comprehension of what was intended, or from a want of acquaintance with what had actually been accomplished in other places, the professional advisers of the Government of India absolutely refused to consent to the construction of these tunnels, and their omission was made a condition of sanction to the execution of the project. Other means, which will be described later, were therefore adopted, which, though ultimately successful, were only rendered so by great labour and devotion on the part of the executive staff, and at a heavy expense of both time and money. To this interference was due a large portion of the difficulties which attended the construction of the foundations of the main dam, and the whole of the annoying and expensive, though less important, interruptions to work which characterised the operations of all but the last two years. The estimates for the works were definitely sanctioned by the Secretary of State for India in 1884; but the Government of India, in spite of the urgent remonstrances of the Madras Government, refused to allot funds for their execution until near the end of 1887, when, somewhat unexpectedly, orders were issued for the immediate commencement of operations.

Before describing these operations in detail, it is necessary to describe briefly the peculiar climatic conditions of the Periyar Valley, as these conditions had an important effect on the progress of the work. From the beginning of April to the end of June, jungle fever is so prevalent and so deadly that engineering operations on any but the smallest scale are impossible. The number of workmen who could be induced to remain on the spot during these months was no more than enough for the maintenance of work already carried out, and both officers and subordinates had to be relieved at short intervals. The working year was thus reduced to the nine months from July to March; and of these months, July, August, November and December were practically useless for work in the river-bed on account of incessant floods, while all other work was impeded by continual

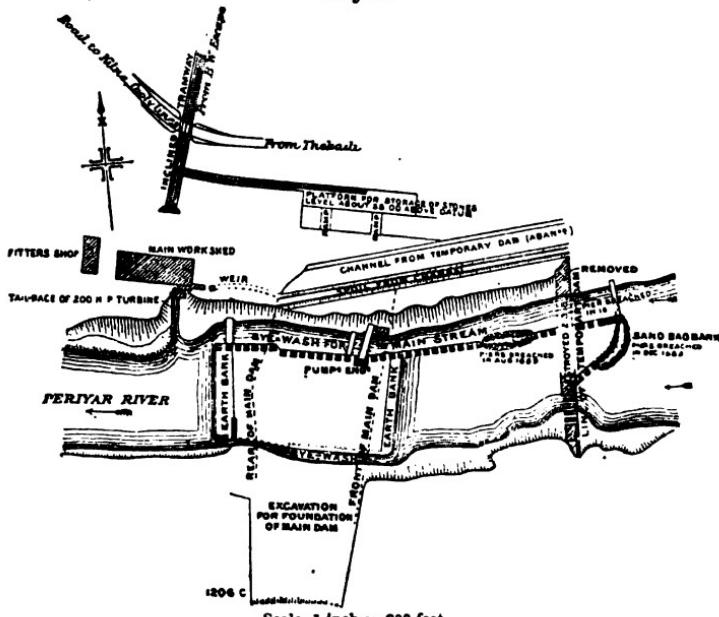
rain. All work which depended upon cofferdams or temporary constructions of any kind had therefore to be finished during the months of January, February and March; and all such work which was not complete and solid by the end of the last month would infallibly be destroyed during the following July. It should also be noted that the site of the dam was in an uninhabited jungle, 7 miles from the nearest point of a cart-road, 20 miles from the nearest cultivated land, and 80 miles from the nearest railway station, which is 320 miles from Madras.

The season of 1887-88 was occupied in the construction of a road from the nearest point of the main road to the site of the dam, houses for the staff and huts for the workmen. These works also occupied a considerable portion of the following season of 1888-89. In the beginning of 1888, the Author went to England to order the machinery required for the construction of the tunnel, manufacture of concrete and transport of materials. He returned in time for the commencement of work in July, but it was not until the end of the year that any attempt could be made to construct the foundations of the main dam. The detailed examination of the site which had been made in the meantime, had shown that the construction of the temporary dams for the diversion of the river would be even more difficult than had been supposed. It was found that, instead of the bed being of tolerably smooth rock at about the level of the datum of the surveys, it contained a large chasm between 40 feet and 60 feet wide, extending down to between 12 feet and 18 feet below the datum level. This chasm, with sides nearly vertical but very uneven, extended over the whole length to be occupied by the dam, and for some distance above and below it. The original intention had been to build small dams of rubble masonry or concrete immediately above and below the area to be occupied by the main dam; and to pass the dry-weather discharge of the river through a channel cut on the right bank, while the space between the two dams was pumped out and the foundation of the main dam was inserted. The mode of construction of the small dams had, however, to be altered on account of the discovery of the chasm referred to.

The flank portions of the upper dam were built during the latter half of 1888; but the season was an unusually rainy one, and no work in the river-bed was possible until the middle of January, 1889. The dam was then extended to the sides of the chasm, which was filled with dry stone on which the central portion was built; the intention being to puddle the dry stone base till it was made sufficiently water-tight to allow of the

space below it being pumped out and the foundations of the main dam put in. It was expected that this would be finished by the end of March, and during this period the discharge of the river is usually so low that it could be taken by the by-pass already prepared without the temporary dam being topped by the water. Such a contingency would have involved the entire destruction of the central portion, as the dry stone base on which the latter stood could not resist the action of falling water. An unseasonable flood occurred at the end of February (usually the driest time of

Fig. 3.

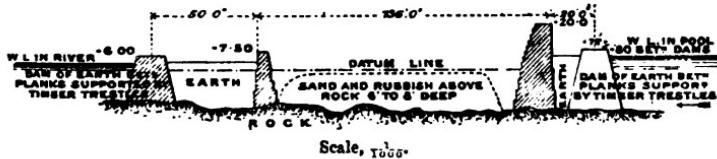


PLAN OF THE SITE OF THE DAM.

the year), when the central portion of the temporary dam was about 6 feet lower than the flanks, so that the whole discharge of the river, amounting to some 4,000 cubic feet per second, passed over the former, which was destroyed. The following plan was then adopted:—a line of piers, *Fig. 3*, 6 feet wide and 6 feet apart, with their crests 13 feet above datum, was built from the right flank of the temporary dam (the two flank portions being undamaged), extending downstream along the edge of the chasm already mentioned to some distance below the rear of the main dam, and upstream in the same way for

about 50 feet, to a point where the chasm was considerably narrower than at the point where the temporary dam had been breached. At the upstream end of this line of piers, a solid wall was built to the same height on the left flank of the chasm, which was filled with sandbags. The setting of these sandbags was by no means easy, as the velocity of the stream was so great that they were carried away like pieces of paper. The lower bags were retained in position by heavy frames of timber, and when once a foundation was made, the upper part of the dam presented no serious difficulty. It may be mentioned that this dam remained without serious injury, although it had at times 10 feet of water passing over it, for two years, after which it was submerged by the rise of the main dam below it.

Fig. 4.



CROSS SECTION OF DAM DURING CONSTRUCTION.

Fig. 5.



LONGITUDINAL SECTION OF TEMPORARY DAM.

When the intervals between the piers were closed by wooden shutters, they, together with the sandbag bank, formed a barrier forcing the water of the river along the right bank. It was calculated that this barrier would not be topped by a discharge of less than about 2,000 cubic feet per second. It would have been desirable to build a solid wall instead of the line of piers and shutters; but the number of masons available was small, and as it was, the necessary work was only just completed before work had to be stopped for the summer. The same necessity for reducing to the utmost the amount of masonry required, caused the Author to adopt a very light section for the piers, only just sufficient to stand the actual water-pressure. As a matter

of fact, several of them were carried away during the succeeding two years by trees brought down the river during floods, but no serious difficulty was experienced in filling the gaps thus caused with sandbags.

It was hoped that, in the interval which usually takes place between the two "monsoons," i.e. from the end of August to the middle of October, the discharge of the river would fall to about 1,200 cubic feet per second, which was the limit above which it was not considered wise to attempt any further work in the river-bed. This hope was not realised, and it was not until the beginning of December that any further progress could be made.

Although the bulk of the discharge of the river was carried by the by-wash on the right bank, there was sure to be considerable leakage through the sandbag bank as well as through the shutters, which were of necessity constructed of unseasoned timber, and at the junctions of the shutters with the piers. This leakage, which was found by subsequent measurement to amount to about 60 cubic feet per second, was far more than could be disposed of by pumping. It was therefore necessary to adopt separate measures for dealing with it, as well as for preventing the river below the main dam from heading back into the space occupied by the shutter. In order to provide for this, accurate sections were taken of the river immediately above and below the site of the main dam. Trestles of timber were prepared, each consisting of two legs 8 feet apart at top, sloping outwards at 1 in 4, cut to the exact length; so that when their tops were 8 feet above datum (or about 5 feet above the normal dry-weather level of the river), their feet rested on the rock at the bottom. The actual lengths of the legs varied between 6 feet and 26 feet. The legs were connected by transverse horizontals at every 5 feet of height, and by diagonal bracing. The trestles were erected in the river-bed, 5 feet apart, and were connected together by rows of longitudinal horizontal members in front and rear. Owing to the great size of some of the trestles, and the limited plant available for moving them, their erection was a matter of some difficulty, and would have been impossible but for the almost still water produced by the upper dam and the by-pass. Sheet piling was then driven down between the longitudinal horizontals, forming a casing 8 feet wide at the top, with front and rear slopes of 1 in 4. Earth was then poured in as rapidly as possible from both ends, all available labour being devoted to this work. In spite of every precaution to make the wooden covering as tight as possible, there was still a certain

amount of leakage, and some earth was lost; but the whole covering was filled in two days. It may be stated here that, in spite of the apparently unpromising material formed by earth thrown at random into 20 feet of water, the dams remained admirably water-tight, and on one occasion only gave trouble by a small slip which was repaired without difficulty.

Two dams were thus formed, one above and the other below the site of the main dam; the leakage through the outer dam being taken up by the upper one and carried past the lower one by a by-pass on the left bank, similar to that on the right bank, but on a smaller scale.

Owing to the state of the river, it was not until the beginning of December that the construction of the cross dams could be begun. By that time the north-east monsoon was apparently over, the discharge of the river had fallen to about 1,200 cubic feet per second, and the clear days and cold nights which characterise the cold weather in these parts had set in. The erection of the trestles was therefore begun on the 5th, and the cross dams were completed by the 15th December. The space between the dams was pumped dry, and the masonry of the foundation was begun. On the night of the 18th, however, there occurred a heavy storm, in which 3 inches of rain fell in four hours. The discharge of the river increased to 6,000 cubic feet per second, carrying away the whole of the upper cross dam and most of the lower one, and seriously injuring the piers and shutters forming the main by-wash. The trestles carrying the 8-inch centrifugal pump were overturned, and, with its pipes, were buried in sand under 20 feet of water. On the night of the 29th a still heavier flood occurred, after which the river subsided gradually; but it was not until the 14th January that the work could be resumed.

The timber-work for a new pair of cross dams having been prepared during the interval, the latter were completed and pumping was begun on the 27th. It was found impossible to raise the 8-inch pump, and the only other one available was a 6-inch pump, by means of which the space between the dams was emptied to 6 feet below datum by the morning of the 30th, when the masonry was re-commenced. This little pump worked admirably, and did nearly the whole of the pumping required during that and the following season; its capacity is stated by the makers at 500 gallons per minute, but it was found by actual measurements on several occasions to be between 800 and 1,000 gallons per minute.

With only two working months remaining, it was not possible to construct the foundations for the whole thickness of the dam, which would have required some 400,000 cubic feet of masonry. It was therefore determined to construct the walls representing the front and rear faces of the dam, and to carry them to such a height as to allow work between them to be resumed, as soon as the discharge of the river fell below the carrying-capacity of the main by-wash. Little difficulty was experienced with the lower wall, which was carried up to $7\frac{1}{2}$ feet above datum—a height considered sufficient to prevent heading back from any flood which did not submerge the whole work. The upper wall presented far greater difficulty. It was found, when the site was pumped out, that the removal of the original upper cross dam was not so complete as had been supposed; and that the framework of the rear face of the new dam, instead of resting on the rocky bed of the river, was resting on the débris of the old dam, consisting of nearly pure sand, all clay having been washed away. The greatest care had to be exercised in the removal of this débris, to prevent the new dam from slipping. The leakage under the latter was very heavy, and carried with it large quantities of sand; the space between the rear face of the cofferdam and the front of the masonry was very small, and the greatest difficulty was found in protecting the latter until the cement had time to set. The work was pushed forward inch by inch from the two flanks, but when the width of the central gap was reduced to about 6 feet at the bottom, the rush of water through it was so great as to render it impossible to build. The cement was carried away as fast as it was inserted, while every day's delay increased the danger of the cofferdams giving way altogether.

It became evident that no measures which could be adopted in the time available would enable this piece to be got in dry, and in order to avoid the loss of another season, the Author adopted the following expedient:—Large gunny-bags were filled with rich concrete and were lowered into the gap, which had been previously cleaned as far as possible of sand and slush; and a foundation was thus made on which the upper portion of the wall was built. This wall was perfectly firm and solid, and showed no signs of movement during the following season, when it was exposed to a head of more than 30 feet of water. The lower part was not water-tight, though the leakage was less than might have been expected, owing, no doubt partly to the cement oozing through the bags, and so uniting them one to another; but mainly, in the Author's opinion, to the puddling of the spaces

between the bags by the natural action of the water. The leakage was never actually measured, but judging from the power required to keep it down in the following season, it was probably about 180 gallons a minute.

Before work was stopped in April, the front wall was carried up to 20 feet above datum, with the exception of a length of 50 feet near the left bank, which was intentionally left 4 feet lower; and the piers of the main by-wash were raised and strengthened so as to increase its carrying-capacity to about 3,000 cubic feet per second. While this work was in progress, it was interrupted by a small flood which passed over the whole work. At this period the rear wall was just completed to its full height of 7·50 feet above datum, and the front wall was at 7·00 feet, except for a length of about 40 feet in the middle, which was 6 feet lower. Not a stone was displaced in the upper wall, and the damage to the lower one was confined to a length of about 20 feet in the middle, where the upper 4 feet was so damaged as to require rebuilding.

On the resumption of work in July, 1890, the first thing necessary was to stop the leakage through the lower part of the central portion of the front wall, and the following method was adopted. Parallel to this wall, at a distance of 10 feet from it, a second wall was built. This work was of sufficient section to support a head of 30 feet of water, and was, of course, made water-tight without difficulty, the leakage through the first wall being removed by pulsometers. The two walls were connected by cross-walls dividing the space between them into cells 10 feet square, which were filled with concrete. Into most of these cells the leakage was insignificant, and the concrete was laid without any special precaution; but in those into which the leakage was considerable, the water was allowed to rise until it stood level with that outside, and the concrete was then lowered in skips. Into each cell was fixed a 4-inch pipe with its lower end about 2 feet above the rocks, and its top about 10 feet above the surface of the water outside. On the top of each pipe was fixed a small cistern, which, as soon as the concrete in the cell was thoroughly set, was filled with thick grout of pure Portland cement; by this means the leakage was completely overcome, and no water ever came through the second wall or up through the concrete in the cells. The remainder of the space to be occupied by the dam was then filled with concrete. The rock on which the dam stands is hard and sound, and free from perceptible fissures, but when exposed to a considerable head of water, numerous minute jets appeared over the area, rising to a height of between 2 feet and 6 feet; these were

all dealt with in the same way. Round each jet was built a small ring of pure Portland cement, carried up until the water within it showed no appreciable tendency to rise; it was then filled in with dry cement.

From this time forward, the work proceeded without serious interruption; such as naturally occurred during the next two seasons, when the whole work was liable to submersion during floods, were neither serious nor dangerous. The most important difficulty encountered, when the foundations of the lower part of the dam had been completed, was in connection with the disposal of the water of the river, which at first was passed by the by-wash described. The use of a tunnel driven through the rock on the flank of the river having been prohibited, it was at first proposed to use two large siphons; but the practical difficulties in the way of moving these from time to time as the work proceeded, and the risk of injury to them during floods, caused this idea to be abandoned before any attempt was made to put it into execution. The course adopted was to pass the water through vents in the front wall of the dam, which was always kept considerably higher than the main portion in rear of it; and the closing of these vents was often a matter of considerable difficulty, while their existence involved a number of joints which could only be made water-tight with great care. The vents were at varying levels, and each one was prepared in advance of the time at which water would be required to pass through it. They were usually so placed that their sills were between 3 feet and 5 feet above the natural ground, and in front of each was built a semicircular platform of masonry, 18 feet in diameter, of which a ring, 1 foot wide and 17 feet in external diameter, was made quite smooth with cement.

When a vent had to be closed, horizontal planks were forced down along the face, making a rough closure and producing practically still water in front of the vent; a semi-cylindrical caisson of iron plate was then set down in front of the planks which were removed, and the vent was built up. The caissons were formed of rows of iron plates, each row containing five plates, 5 feet wide and 4 feet high, bent to a curve of 8 feet radius; so that the whole formed a half cylinder, 16 feet in diameter and 20 feet high. The joints between the plates were covered by angle-bars bolted to the main plates; the angle-bars covering the horizontal joints being bent to the same curve as the plates. As the time chosen for sinking the caissons was always when the discharge was very low, only the bottom two rows of plates had

to be made before being let down, the upper rows being built on as required. These caissons answered admirably, making an excellent joint, the leakage through which never amounted to more than a boy could easily bale out; while the semicircular shape gave ample room for the masons to work inside, and to make a true joint between the old work and the closure of the vent.

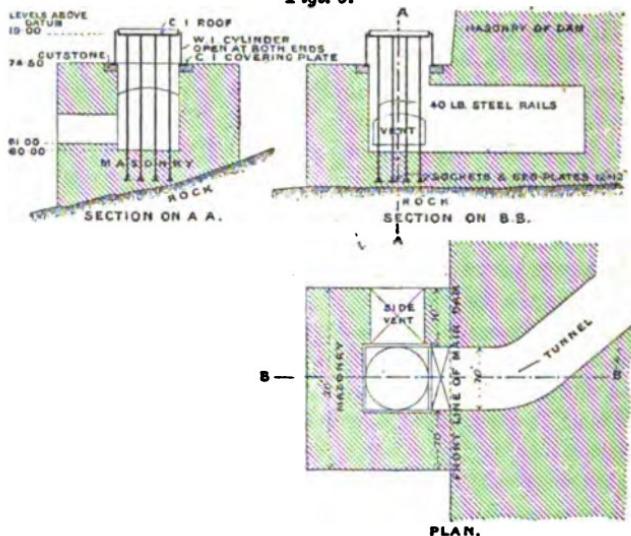
As a rule the water was not raised more than about 8 feet at a time, that is to say, a vent was prepared with its sill not more than this distance above that of the one to be closed; and the only occasion in which any serious trouble was experienced in the operation of closing, was when a lift of nearly 20 feet was attempted. In this case a moderate flood occurred while the closure was in progress, the lake rose faster than was expected and topped the caisson, the upper part of which was at the same time damaged by a tree brought down by the flood. The difficulty was ingeniously met by sinking a barge loaded with stone over the top of the caisson, and under cover of the protection thus given, the closure was, though with some trouble, completed.

Although these arrangements worked well, the existence of the vents was a constant source of annoyance and anxiety, apart from the difficulty of closing them. They rendered it necessary to keep the front wall of the dam a considerable height above the remainder, and to leave passages for the water through the whole thickness of the dam, which interfered greatly with the movement of the workmen along the top of the work and with the supply of materials. They effectually prevented the work from being kept at a nearly uniform level from end to end, a condition which the Author considered highly desirable. On one occasion, when a spell of wet weather prevented the closure of any vent for a longer period than usual the difference of level between the floor of the lower vent and the work on both sides of it became so great as to cause some anxiety. In 1892, it was therefore determined to construct a vent of more permanent description, through which the water might be discharged until the work was completed. It was considered that at the level (60 feet above datum) at which the sill of this vent would be placed, the objections to a tunnel near datum level would not apply; and that the conditions were so altered that the pledge that no such tunnel should be constructed, need no longer be binding. A tunnel with an area of 100 square feet was therefore left, running through the dam, with its sill 60 feet above datum. The axis of the tunnel was at right-angles to the face of

the dam for a short distance, and it was then carried round to form an angle of 45° with it, so as to make the closure more secure.

The entry of water to the tunnel was controlled by a sluice, *Figs. 6*, consisting of a masonry chamber 10 feet by 13 feet, with walls 10 feet thick, built in front of the mouth of the tunnel. The top of the walls was $14\frac{1}{2}$ feet above the sill of the tunnel, and the 3 feet nearest the dam was arched over, leaving an opening 10 feet square, which was covered by a cast-iron plate 11 feet square, with a circular opening 10 feet in diameter. An iron roof, of the same size as this opening and

Fig. 6.



Scale, 1 inch = 32 feet.

SLUICE FOR THE TUNNEL THROUGH THE MAIN DAM.

immediately above it, at a height of $4\frac{1}{2}$ feet, was supported by twenty-four steel rails, weighing 40 lbs. to a yard, arranged in two circles, and built into the floor of the chamber; so that the water could reach the tunnel only through the cylindrical space between the roof and the covering plate of the chamber. This space was covered by a wrought-iron cylinder, open at both ends, large enough to pass easily up and down outside the iron roof. The steel rails were fitted at the top and bottom into cast-iron sockets, with bed-plates 6 inches square for the top and 12 inches square for the bottom; the former being bolted to the iron roof and the latter built into the concrete forming the floor of the chamber.

The sockets were provided with set-screws to enable the uprights to be accurately adjusted. The outer ring of uprights were further steadied by being passed through brackets bolted to, and projecting from, the covering plate of the chamber. Guides were provided for the moving cylinder. The water having free access round the whole circumference of this cylinder, the latter moved up and down without friction, and the discharge through the tunnel was under complete control. The lake could be maintained at any required level provided the discharge of the river did not exceed the quantity (1,500 cubic feet per second) which it was considered that the tunnel could carry without injury to the masonry. When this discharge was exceeded, the lake had to rise until it passed over the dam. The strength of the different parts was calculated for a depth of 60 feet on the sill of the tunnel; as it was considered that it might be necessary to use the latter, until the water was able to pass over the middle on the left flank of the river. It was not, however, required to carry more than about 20 feet. A vent which could be closed at will was left in one of the side walls of the masonry-chamber, in order that the lake might, during the dry weather, be run down to below the top of the chamber. The benefit of this tunnel was felt immediately in the increased rate of progress which was rendered possible by the work being brought to a nearly uniform level over its whole area, and by the removal of the obstructions formed by the gangways and bridges necessitated by the former arrangements.

By the end of March, 1895, the dam having been brought up to 118 feet above datum, and a temporary escape having been prepared on the left bank saddle, the tunnel was closed. The operation was greatly facilitated by the abnormal, and, so far as the observations of the staff showed, unprecedented drought which prevailed at that time. The discharge of the river fell so low that the vent in the side of the chamber was sufficient to keep the lake to about 65 feet above datum. When this vent was closed the lake rose so slowly that the tunnel was built up for a thickness of 30 feet before the water rose to the top of the chamber. After this there was no further difficulty or trouble in connection with the dam, which was raised high enough to allow water to be sent through the watershed tunnel into Madura in October, and entirely completed in March of the following year; but the saddle on the left flank gave a certain amount of trouble.

It had originally been intended to close this saddle by a dam with

its crest at 144 feet above datum, to serve as a permanent escape, supplemental to the one on the right bank. When, however, the rock came to be laid bare, it was found to follow the section shown on the original surveys only as far as the lowest point of the saddle, just beyond which a considerable fault occurred; and the rock, instead of rising as was expected, fell very suddenly as shown on the section, *Fig. 1*. It was followed down to about 90 feet above datum without showing any signs of rising; the hillside above it was composed of very treacherous material, full of springs and continually slipping, which rendered excavation difficult and expensive. It became evident that to get down to rock sufficiently sound to build upon, would involve an expense out of all proportion to the object to be attained; while the water of the lake could not be kept at a lower level than between 115 feet and 120 feet, and might not improbably break into the excavation and scour away the soil until rock was reached.

The Author considered the propriety of allowing this to happen; but, as it was known that the dip in the rock went down at least to 90 feet above datum, and possibly a good deal lower, it was certain that this course would involve at least a year's delay in the completion of the work. The advantage of the additional length of escape provided by the original design, was certainly not such as to counterbalance this drawback. It was therefore determined to build to the same section as the main dam as far as the solid rock extended, that is, to about the point marked *x* in *Fig. 1*; and thence to build an earthen bank with its crest at 170 feet above datum, or 15 feet above the top of the masonry dam and 17 feet above calculated maximum flood-level. The end of this bank was allowed to slope at 2 to 1 in rear of the masonry dam, and was supported in front of the latter by a massive wing-wall, the highest part of which, nearest the masonry dam, was founded on rock; the end portion was not on rock, but on soil sufficiently good to cause no anxiety as to the stability of the wing. The foundations of this wing were inserted while the lake was rising, and were completed before the water passed over the temporary escape. Dry-stone drains were built at as low a level as possible, to convey to the rear the water coming from the hillside in and above the area covered by the bank, and no sign of slipping has yet been observed, nor is any anticipated.

The main dam consisted of a front and rear wall of rubble masonry, defining the outer faces, the space between them being filled with concrete. The thickness of the rubble depended partly on the number of masons available, and partly, especially in the earlier

stages, when the front wall was considerably ahead of the concrete backing, on the head which the former might have to stand before it was supported by the latter. On an average, the rubble formed about 30 per cent. of the whole. The mortar used was made from "Kunkur" lime brought from the Madura district about 17 miles from the dam, mixed with a small quantity of "surki," or burnt clay finely powdered; and for concrete the mortar was always mixed before the stone was added to it. Portland cement was never used except for work to be exposed at once to the action of water; the mortar was of admirable quality, blocks six months old having borne 1,200 lbs. on the square inch without crushing, while concrete blocks 1 foot square bore 80 tons. The tests to which both masonry and concrete were subjected during floods were numerous and severe, and in no single instance was any failure or even weakness observed.¹

The greater part of the stone for concrete was broken by six stonebreakers, driven by a 200-HP. turbine, the power for which was obtained from the river. The same turbine worked a wire ropeway for conveying materials from the workshops to the dam, disintegrators for grinding lime and surki, with auxiliary machines, and, at first, mortar and concrete-mixers for the manufacture of concrete. These were abandoned after a time, as it was found that the machine-mixed concrete was not as good as that mixed by hand; and had in fact to be re-mixed on the work before use, while the machine-mixed mortar was not as good as that made in ordinary pan-mills. The workshops containing the machinery were situated on the river bank, a short distance below the main dam. The water for supplying the turbine was led from the by-wash by a wall built along the bank with its crest 25 feet above datum, giving a working-head of about 20 feet, the wall serving as a weir for the passage of surplus water. A self-acting tramway on a gradient of 1 in 4 conveyed the stone from the escape to the stonebreakers. During the last three years of the work, it was found that the workshops could not supply the stone as fast as it was wanted; and two more breakers, worked by steam, were erected on the escape, the stone from them being sent direct to the dam by shoots laid down the hillside.

¹ Since the Paper was written information has been received that in July, 1896, a flood occurred, which raised the level of the lake to 6½ feet above the crest of the escape, or 150½ feet above the datum of the surveys, giving a depth of 168½ feet of water against the face of the dam. This was a somewhat severe test, as the upper part of the dam was only completed in March, and it is satisfactory to know that no signs of weakness have appeared.

The transport of materials, including about 80 tons of limestone daily, and the whole of the food for between 4,000 and 6,000 men, was difficult and expensive. The main road from Madura to Travancore passes within about 1 mile of the entrance to the watershed tunnel, and about $7\frac{1}{2}$ miles from the site of the dam. From this point a road was made, along which supplies could be taken; but the cost of carriage by cart was exceedingly high, and water-carriage was used as far as possible.

The watershed cutting and tunnel start from the bed of a small tributary of the Periyar, canalized by locks and dams, forming, when in use, a much cheaper mode of transport than the road; but the stream usually ran dry towards the end of January, and from then till July the road had to be used. It is a subject of regret to the Author that he did not adhere to his proposal to build a light railway from the watershed to the site of the dam; which, though high in first cost, would ultimately have proved cheaper, as well as more efficient, than the combined system of road and water-carriage actually adopted. From the watershed, the main road descends to the plains of Madura by a "ghat" 4 miles long, with a gradient of 1 in 16. To avoid the excessive cost of carriage of limestone up this "ghat," which was under the charge of the Madura District Board, a wire ropeway, 3 miles long, was constructed and did admirable service, though expensive in first cost owing to the difficult nature of the ground over which it had to be taken. Some of the posts were more than 80 feet high, and in places difficult of access. This ropeway was driven by a turbine worked by the same water as that for the six compressors of the watershed tunnel; but the water rarely lasted beyond the middle of January, and after that date road traffic had occasionally to be resorted to; though for the most part the ropeway carried enough material during the working months to supply the works for the whole season.

The original alignment of the tunnel was carried out by the Author personally, and a few words of description of this operation may be of use. The section (*Fig. 1, p. 142*) shows that the line passes over six separate ridges with valleys between them. The slopes of the hillsides are very steep and are clothed with heavy jungle, and to bring out the line in the ordinary way would have been difficult, and more laborious than at that time could be undertaken. The ends of the line having been fixed, a chain-and-compass survey was run from one to the other by a circuitous route, the greater part of which was on the road, and the magnetic bearing of the two ends was ascertained by plotting this survey. On the top of

each hill in the line thus roughly calculated, a temporary mark was made, and the distance of these points from one another was observed by means of an Eckhold omnimeter. By observing the horizontal angles between the successive lines joining these points with the same instrument, their deviation from the true line joining the ends was calculated. This process was repeated three times, until the line was considered to be fixed with sufficient accuracy; and, for a starting-point at the north or lower end of the tunnel, a bench-mark was fixed on the further bank of the ravine into which the tunnel debouched, giving a length of about 120 feet from which to start the alignment. The advantage of this mode of working, was that the observations were made entirely from the crests of the hills, and all measurements on the slopes and in the valleys were avoided. The result was to give the Author a very high opinion of the value of the omnimeter, which he had never used before. The two faces met with a horizontal error of 0·15 foot, and the calculated length was found to be within 24 feet, or 0·4 per cent., of the truth.

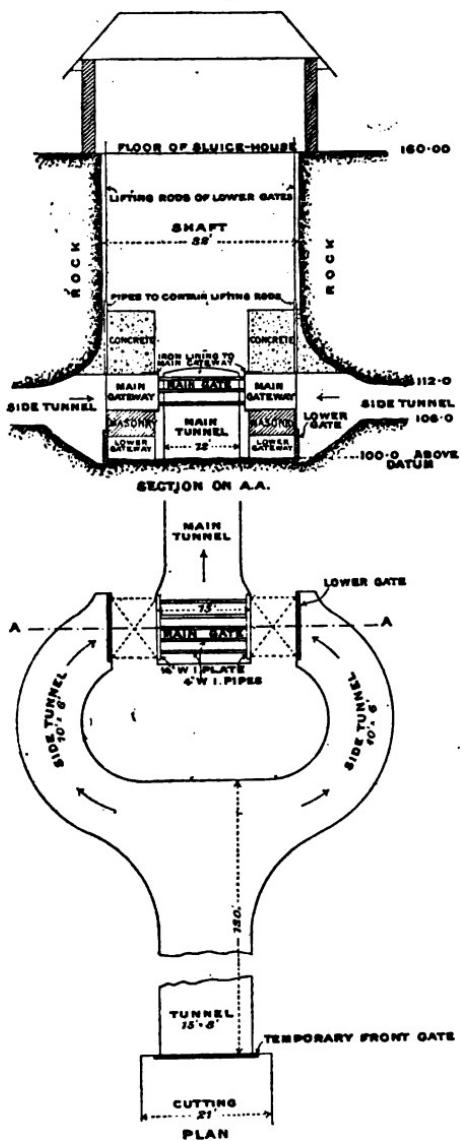
The construction of the tunnel through the watershed ridge presented several features of interest; and this portion of the work forms the subject of a separate Paper by one of the officers employed in its construction.¹

In the sluice controlling the entry of the water to the tunnel, *Figs. 7*, the tendency of the pressure is to force the shutters inwards, and the distance-pieces have to act as struts. They are therefore made of pipes 4 inches in diameter. The lower set of gates were added, in order to provide means by which a minimum supply of 500 cubic feet per second could be sent down, when it was necessary to close the main gates for the purpose of examination and repair. There is certain to be a good deal of wear on the lower edges of the gates and gateways. As long as irrigation only had to be considered, this was immaterial, as there would be about two months in every year during which no water was required, and the necessary repairs could always be executed during this period. If, however, water should be required for the development of power, it is essential that the supply shall be constant; and during the deliberations of the committee appointed by the Secretary of State in 1893 to consider this subject, the Author undertook to modify the design of the sluices so as to allow of a minimum of 500 cubic feet per second being sent down without intermission.

¹ "The Periyar Tunnel," by Mr. P. R. Allen, *post*, p. 164.

Under ordinary circumstances the lower gates will be closed, the supply for irrigation being regulated by the upper main-gates.

Figs. 7.



Scale, 1 inch = 32 feet.
SLUICE FOR THE MAIN TUNNEL.

be repaired without difficulty. The operations of putting down the front gates and of opening the lower gates, will each occupy only a few minutes; and it is only during these periods that the water need be shut off entirely from the tunnel. The latter contains more than 500,000 cubic feet, which will supply 500 cubic feet per second for more than a quarter of an hour. The lower gateways being ordinarily closed, and, when in use, under a head of only about 5 feet, will not be subject to any appreciable wear and will last for many years; but the main gateways, having to pass water with a velocity that may reach 40 feet per second, will require pretty frequent repair.

The result of the operations described, has been the formation of a lake with an area, at the lowest level to which it can fall, of 164 million square feet, or 3,765 acres; at the level of the escape, the lake has an area of 279 million square feet, or 6,405 acres, which may be increased to 7,454 acres, or nearly 12 square miles during heavy floods. The whole of the water stored above the first-named level, amounting to 6,815 million cubic feet, is available for counteracting the fluctuations in the natural discharge of the river, which has been carefully recorded for several years—varying between 400 million and 12,000 million cubic feet per month, the average annual discharge being about 35,000 million cubic feet. The water thus stored, after passing through the watershed tunnel, is conveyed by natural watercourses for a distance of more than 80 miles (in the first mile of which it falls about 1,200 feet) to an existing “anicut” on the Vaigai River, at which it is directed into the channels constructed for its distribution for irrigation.

The distribution-works, though presenting no special features of engineering interest, are extensive, and from their geographical position somewhat costly. They comprise a main channel 38 miles long, adapted to carry 1,600 cubic feet per second at its upper end, diminishing to 300 cubic feet at its lower end; with twelve branch-channels, aggregating about 93 miles in length, carrying between 100 cubic feet and 300 cubic feet per second, and somewhat more than 100 miles of minor distributaries.

The head sluice, which regulates the passage of water from the Vaigai to the main channel, contains eight vents of 12 feet span and 6 feet lift. The shutters are worked by double screws, the heads of each pair being connected by chains which compel them to work in unison. The sluice is capable of passing the full supply required for irrigation under it, with a head of somewhat less than 6 inches.

The main channel runs along the foot of the Simmalley hills, and has to pass the whole of the cross drainage from their slopes ; this is effected for the most part by super-passages, though in a few instances aqueducts have been used. The cost of these works has formed a very large portion of the total expenditure.

The total cost of the works has been Rs.85,00,000—at the present rate of exchange about £500,000—including all charges for establishment and plant. Of this sum, about Rs.60,00,000 is chargeable to the head-works in the Periyar valley, and Rs.25,00,000 to the distribution-works in the Madura district. The main dam, containing about 6,000,000 cubic feet of masonry, and the escape cost together Rs.30,00,000, and the cutting and tunnel through the watershed Rs.8,00,000. In addition to the capital expenditure, an annual payment of Rs.40,000 is to be made to the Travancore Government for the right to divert the water of the river. The direct return from irrigation is estimated at about Rs.720,000 annually, from which has to be deducted the cost of maintenance and management, estimated at Rs.1,25,000, and the payment of Rs.40,000 to Travancore ; leaving a net return of Rs.5,55,000, or 6·53 per cent. on the capital expenditure. There is, however, in addition a sum which cannot at present be estimated, for sale of land now occupied by beds of tanks which will be rendered unnecessary when the works are completed, and occupation rights on waste land, now the property of Government, which will be brought under cultivation. It is probable that the ultimate return will not be less than 7½ per cent. on the capital expenditure.

There is, moreover, a further source of revenue already referred to which the Author believes will in the near future approach, if it does not equal, that from irrigation. The water from the mouth of the tunnel falls about 1,200 feet in the first mile, and can be utilized for the development of mechanical power without in the smallest degree interfering with the requirements of irrigation. The average amount of water to be sent down throughout the year is about 1,000 cubic feet per second ; but the amount required for irrigation varies at different seasons, and the minimum which can be sent down without interference with these requirements, which must be considered as paramount, is about 600 cubic feet per second, representing some 60,000 HP. The conditions for the development of this power are singularly favourable, as the steepness of the valley allows of short lengths of supply-pipes in relation to the fall ; while the works for the storage and regulation of the water-supply, which form so heavy an item in the cost of most water-power schemes, are already in existence. At present

there is no great demand for power in the immediate vicinity of the works; but the electrical transmission and distribution of power is progressing so rapidly, that it would be rash to assert that it will not be found possible, before many years are past, to utilize this power in the large towns of Madura and Trichinopoly, or even in others still more distant. A Report¹ on this subject was made in 1893 by a committee of which the Author was chairman, the members being Professors Forbes, Unwin, and Roberts-Austen. Applications for the right to use a portion of the water for this purpose have already been received by the Government of Madras, and it is understood that negotiations on the subject are in progress; other applications will no doubt follow.

The Author has endeavoured to confine himself as far as possible to a plain narrative of the course of operations, but he finds it impossible to quit the subject without a word of acknowledgment of the services of the executive staff employed upon the works. The record of events given in the Paper conveys no idea of the labour, anxiety and responsibility, to say nothing of actual physical danger, caused by the emergencies that arose from day to day, or of the skill and devotion with which these were met. The duties of the Author were mainly those of general supervision, and though no important step was taken except with his knowledge and by his orders, the execution of details was left entirely to the executive staff, who were in no single instance found wanting. Except for a period of about six months, the Author was the only Royal Engineer employed upon the works, the remainder of the staff being civilians, trained, with one exception, at the Royal Indian Engineering College, Cooper's Hill; and both during the progress of the works, and during the five-and-a-half years in which he was at the head of the Public Works Department of the Madras Presidency, he experienced the most loyal and devoted support.

The Paper is accompanied by six drawings, from which the *Figs.* in the text have been prepared.

¹ Records of the Government of India Public Works Department, No. ccxv., Calcutta, 1886.

(*Paper No. 2832.*)

“The Periyar Tunnel.”¹

By PARKER ROSCOE ALLEN, Assoc. M. Inst. C.E.

THIS Paper describes the construction of the tunnel through the Travancore mountains, by which the waters of the Periyar are conveyed from the western side of that range, to the Madura district on the eastern side.

The tunnel through the watershed ridge is approached, at its entrance, by an open cutting, of which 3,000 feet are level and 114·94 feet above datum, and 2,342 feet with a slope to the entrance of 1 in 320. The bed-level at the entrance is 107 feet above datum. This cutting is 21 feet wide at the bottom; where this cutting is in rock the sides are vertical, where through earth the slopes of the sides vary between 2 and 1½ to 1. It deviates little from a straight line, and that only where necessary to keep the line in the lowest ground available. At a point 131 feet from the inlet, the main tunnel terminates, and a tunnel branches off on each side at right-angles to the main tunnel line, the direction of each being straight for a distance of 4 feet; then, after each pursuing a semicircular course of 25 feet radius, they rejoin the main tunnel on opposite sides, their final course being at right-angles to the main line and straight for 6 feet before joining it. By this means, the lake is made to discharge into the main tunnel through orifices of equal areas situated on opposite sides of the tunnel. The arrangement was devised to accommodate a sluice suitable for regulating the discharge, which could at the same time be manipulated with ease.

The sectional area of the tunnel, as designed, is 80 square feet, but as executed it is nowhere less than 90 square feet, it being difficult and expensive, with high explosives, to arrange so as to cut the sectional area to a nicety. The slope of the floor is 1 in 75 throughout, and the section will be left in the rough as blasted out.

¹ *Ante*, p. 140.

Throughout its entire length, the tunnel penetrates granitoid rock differing in parts slightly in hardness and in the proportions of its ingredients. In places, the colour was a dull grey; and again in parts the prevailing colour was red; this latter variety was exceedingly hard and tough, difficult to work and trying to the drills. It usually occurred where the rock was quite solid. The rock is in places much broken up with fissures which would seem to communicate with the surface, as some pass small streams of water which diminish in volume after tapping. In one case, some 1,700 feet from the outlet, a small swamp situated on the surface near the tunnel line and some 209 feet above the bed-level of the tunnel at that point seems to have been drained by these streams. A considerable number of fissures passing water were met with for 150 feet at the tunnel entrance, but for the next 2,300 feet the rock was for the most part solid and the tunnel entirely dry. For the remainder of its length, the rock was much fissured and split, and a certain amount of water was met with all along. The fissures have a general direction at right-angles to the tunnel line, and a dip of between 30° and 80° south.

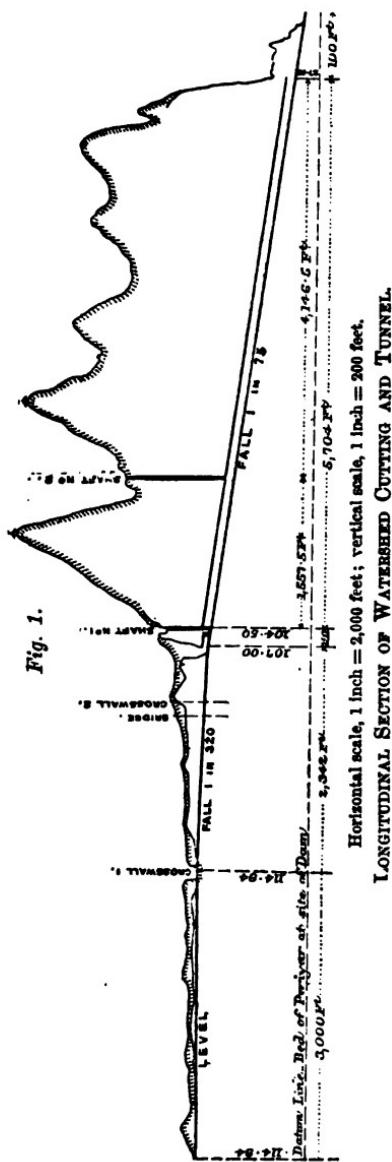
On issuing from the tunnel, the water will fall down the Gudalur Ghauts, some 1,200 feet, the incline being 1 in 4. This volume of water falling from so great a height represents a large amount of power, and attention has of late been directed towards it with a view to putting it to some use.

EXCAVATION OF THE TUNNEL.

The tunnel was driven from three places—*Fig. 1*; work being commenced in 1888 at the exit (the north end) and at shaft No. 1, which was sunk directly over the site of the sluice. Later, work was commenced at shaft No. 2, situated 1,557·54 feet from the entrance to the main tunnel, and 4,146·40 feet from the exit.

Machinery.—At the north end the boring was by rock-drills driven by compressed air, the air-compressors being worked by a turbine. The water for the turbine was stored in a small reservoir situated by the side of the Travancore road, which latter formed the bund to retain the water. From the reservoir the water was conducted, in open cut and wooden flume, to a small masonry reservoir, immediately above the turbine. Water was available from the 1st of June to some time in January as a rule; in years when the monsoon did not fail, and the drilling at that end was at a standstill for the remainder of the year. In 1892, a year of scarcity, it failed on the 17th of November. In

this connection it must be borne in mind that, when drawing up

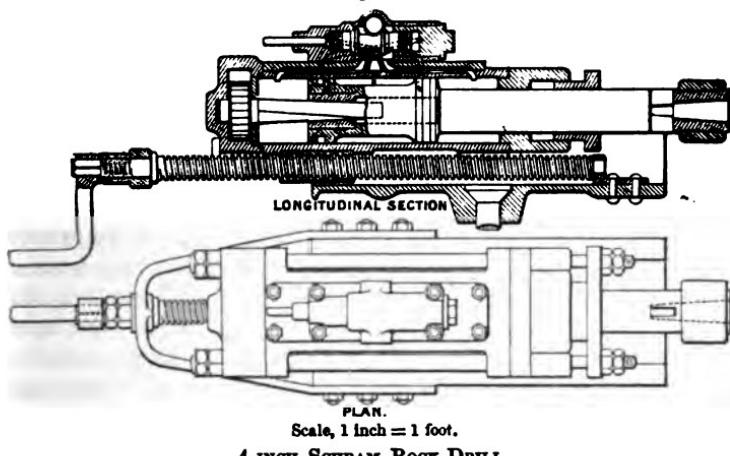


so that at any time the compressors might be disconnected without stopping the turbine or disturbing the main driving-belt. The

water-supply pipes were wrought-iron, lap-welded, screwed and flanged, held together by bolts with india-rubber rings between the flanges.

The air-compressors were two in number, the cylinders being 16 inches in diameter and 24 inches stroke. They were enclosed in cold water cooling-tanks, and were fitted with Schram inlet-and outlet-valves, by means of which the suction between the valve and the valve-seat is overcome, and the efficiency increased. The compressors were coupled to one crank-shaft, the cranks being fixed at right angles to each other, so as to obtain a uniform motion and equalize the resistance. On the crank-shaft were two steel spur-wheels, geared into which were two steel pinions

Figs. 2.



Scale, 1 inch = 1 foot.

4-INCH SCHRAM ROCK-DRILL.

which were keyed on to a counter-shaft; on the counter-shaft a belt-pulley was fixed, having a heavy rim which acted as a fly-wheel. The compressors were driven by a 50-HP. turbine, running at 500 revolutions per minute. This power was transmitted by a double leather belt 12 inches wide. In order to obtain the required speed for the compressor, a counter-shaft was adopted on which were two pinions working into spur-wheels on the crank-shaft of the compressor.

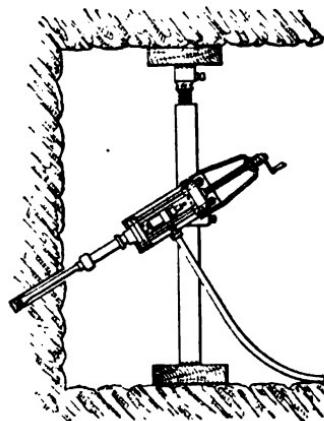
The air was conveyed to the rock-drills through 4-inch wrought-iron pipes provided with screwed flanges which were held together with four bolts, the joints being made with india-rubber rings. The drills used, *Figs. 2*, were Schram 4-inch rock-boring machines. During the progress of the work, various improvements were effected

in the design of these drills, the most important of which was an arrangement for taking up the wear in the cradles. Still further improvements have been effected more recently; the feed-screw nut and its attachment have been improved, a new and stronger ratchet-and-pawl have been adopted, and a new tooth-holder with increased taper.

Shaft No. 2 was sunk by hand through 109 feet of rock, and work was subsequently carried on at the two faces north and south by 4-inch compressed-air rock-drilling machines, the air being compressed by steam. Three of the boilers were of the Root pattern, which adapts itself well to any mode of transport, the packages of a 15-HP. boiler not ordinarily exceeding 4 cwt. 3 qrs. 4 lbs., and capable of being reduced to 1½ cwt. in weight. This, in remote places in India, is a great, if not the paramount, consideration. Along almost all the trunk roads of India, it is difficult to arrange for the transport of loads weighing more than 8 cwt. and measuring more than 15 feet in length or 3 feet in breadth, whilst along by-roads the weight must be still further reduced. All the compressor-plant in use on the tunnel, together with the Root boilers, could, with the greatest ease, be packed on country carts and sent anywhere those vehicles could travel.

At the north end the drills were working under fairly favourable conditions, but at shaft No. 2 it cannot be said they were at any time working under other than adverse conditions, due principally to the use of larger drills than the plant was intended for. Difficulty was experienced in providing enough steam to keep the engines going, and the output does not show what the drills are capable of. Machine work was stopped for a time at shaft No. 2 in February, 1893, the season being so dry that there was insufficient water to supply the boilers. Work was therefore continued by hand until the 1st of June, in order to find work for the men. Some work was done at shaft No. 2 with the "Optimus" compound drills, which were used after the 1st July, 1893. At this time a water-bearing fissure was struck at the north face, and gave such trouble that working at the north face had for the time to be abandoned, and all the force was put to work on the south face only. This, however, did not prevent the necessity of pumping. Previous to this, no trouble had been experienced with the water, and such as trickled into the tunnel had been taken out each morning in a tramway wagon. A pump had, however, now to be placed in the pit and worked for six hours daily. The amount of firewood consumed did not increase with this extra duty, on account of the economy of the new drills.

Method of Operations.—The machines, stretcher-bars, drills, distributors, hose, &c., were drawn up to the face on trucks specially designed for the purpose. The stretcher-bars were secured by wedges and are of the usual type. The 4-inch wrought-iron pipe which conveyed the air from the receivers was connected by a 4-inch flexible pipe to a distributor which divides the supply into two branches, each connected to other smaller distributors by 2-inch flexible hose; and these again each divided the supply into two more branches, every branch of which supplied air direct to one machine through a 1-inch flexible hose. Four machines could thus be supplied simultaneously and independently. The method of mounting the drills is shown in *Fig. 3*. The centre-cut system was followed where the work was executed by machine drills. The four centre holes, 14, 15, 28, 29, *Fig. 4*, were drilled from the corners of square 4 feet 6 inches wide; the inclination being such that they would meet at the apex of a pyramid, 5 feet to 6 feet from the face. The holes in the next row were drilled with an inclination towards the centre of the face so as to facilitate the work of the charge; the next row was straight, and the last row slightly inclined outwards to preserve the full section; this last description applies also to the bottom and top line of holes. Each hole was begun with a 1½-inch steel drill with a bit shaped as in *Fig. 5*, and completed with a 1¼-inch steel drill to prevent any chance of jamming, and with a bit shaped as in *Fig. 6*. The bit in *Fig. 5* was found to be well adapted to begin the holes only; further than this it proved unsatisfactory, as it stuck in fissures and drilled a five-grooved hole. That shaped as in *Fig. 6*, proved eminently satisfactory, drilling a perfectly round hole and never sticking in fissures. The holes being all bored, the machines, &c., were again packed on the trollies and taken back some 600 feet to 1,000 feet, to be beyond the risk of injury from the blasting-operations. It took between nine hours and twenty-four hours to bore the holes, according to the efficiency of the machinery, the supply of motive power and the character of the rock. With efficient machinery and plenty of motive power, in

Fig. 3.SCHRAM ROCK-DRILL MOUNTED ON
TUNNEL COLUMN.

the class of rock in this tunnel, the holes could always be bored in nine hours. The charge for each of the four centre-holes was 5 lbs. of gelatine well pressed in so as to fill the hole. The Bickford instantaneous fuse was used for these four centre-holes, with four branches from 7 feet to 9 feet long (preferably 9 feet) each. To this was attached a time fuse of the requisite length, usually 6 feet. These charges were well tamped with clay tamping, and having been fired, the next lines at the sides and top, nearest the vacancy made, were charged and fired; after those, the side rows were charged and fired. The bottom row of holes were usually loaded and fired last, and it was always necessary, before attempting to charge them, to clear away the débris covering them. 50 lbs. of gelatine was generally used amongst these thirty-eight to forty holes; the charge being nearly always equally divided,

Fig. 4.

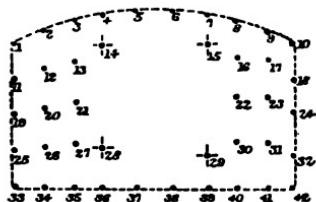


DIAGRAM OF FACE, SHOWING POSITIONS OF HOLES.

Fig. 5.

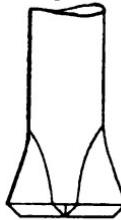
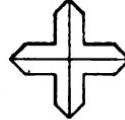


Fig. 6.



but liable to any little alteration which circumstances seemed to necessitate. The tamping used was invariably good clay, and was well rammed. The fuse was the Nobel rubber-felted double-wove safety fuse. All the explosives were obtained from the agents of the Nobel Explosive Company.

As soon as all the holes were fired, men were called in to remove the débris. This clearing usually took twelve hours to accomplish, and, when completed, the machinery was set up again as before. At the north end, the number of men found necessary to remove the débris after the blasting operations, varied between forty men with two sets of wagons of four trucks (each set with a lead of 700 feet) and eighty men with four similar sets, with a lead of 2,700 feet. At shaft No. 2 the number of men varied between thirty-five with no lead and forty-eight with a lead of 700 feet.

Until water was met with at the north-face of shaft No. 2, the machinery was erected alternately at the north and south faces. After water was met with in July, 1893, the south face only was worked until it was nearly through; and in November, 1893, work was there stopped and the north face was proceeded with. This was effected by pumping the tunnel dry, blasting out a reservoir at the face, and pumping all the leakage-water up the shaft. The experiment was successful for a time, so far as the Author is aware; it was afterwards abandoned, the remaining portion being completed from the north end as soon as the advent of the south-west monsoon rains permitted work to be recommenced.

Tramway Plant.—For the removal of débris from the tunnel, a portable tramway of 2-foot 6-inch gauge was laid, single line, with sidings where necessary. This consisted of light 12-lb. steel rails, with steel sleepers, attached by means of nuts and bolts to the rails. At the north end, there were eight to sixteen end-tip wagons, according as the lead varied, each wagon holding 16 cwt., worked in trains of four wagons and drawn by ponies. At shaft No. 2, side-tip wagons were used, the capacity of which was also 16 cwt. They were worked in trains of four wagons, and the train was drawn up from the north face by a steel-wire rope, which passed up the shaft, and was worked by a 5-ton crab-winch. Those working at the south face were hauled by coolies, the gradient being a falling one. On arriving at the bottom of the shaft, the wagon was hooked on to another steel-wire rope and was hauled up the shaft by the hoisting-engine. At shaft No. 1, side-tip wagons worked by hand only were used. These were hauled up the shaft by a windlass worked by bullock power.

Ventilation.—At the north end, the tunnel was ventilated by a fan designed to exhaust 6,000 cubic feet of air per minute, placed just outside the tunnel exit, and worked by a 6-HP. turbine, with 180 feet fall. This fan was in communication with an air-flue, 3 feet square in section, made in lengths of 15 feet of 1-inch planking, the joints being covered with $\frac{1}{2}$ -inch planking. At shaft No. 2, about one-third of the tunnel section was cut off by a vertical partition made of 1-inch planking, fitting the irregularities of roof and floor. The flue so made was connected to a partition in the shaft, and this, again, was in direct communication with the hearths of all the Root boilers, so that an upward draught was induced.

Pressure of Air.—At the north end, the 4-inch wrought-iron piping, which conveyed the air from the receivers to the machine, was laid in the side drain. This arrangement afforded facilities

for protecting the flange from injury, and was otherwise convenient. At 3,000 feet from the receivers, there was a constant loss of 10·38 per cent. At shaft No. 2, the pipes were laid quite dry in the air-flue, and at 1,200 feet from the receiver it was found impossible to detect any loss. The working pressure for the 4-inch Schram drill was 30 lbs. per square inch, and for the "Optimus" compound drill 60 lbs. per square inch.

Fuel.—Considerable attention should be paid to the selection of good wood for use as fuel, otherwise much time is wasted in raising steam and also in keeping the pressure. The woods used as fuel were:—Teak, benteak, vengai, angelly, nelly, kadookay, kadha maruda, tella maruda, vaccali, and blackwood. Of these, the best was teak, while vengai and nelly rank next. Tella maruda was inferior, and only a small quantity of it was admitted. The limiting sizes were:—Length baulks 2 feet, and breadth between 6 inches and 3 inches.

Labour.—The number of men employed at the north end, shaft No. 1 and shaft No. 2, were 109, 42 and 131 respectively. The machine-men and coolies for removing spoil were all paid one day's wages for a shift of eight hours and for overtime at the same rate. For the remainder, the day was nine hours, except for engine-drivers and firemen, whose day was twelve hours. All coolies working underground received 8 annas a day. Each drilling-machine required two men to work it. The blacksmiths were all Northern India men, and were not very skilful.

Cost of Boring.—The cost of boring the tunnel at shaft No. 1, shaft No. 2 and the north end was Rs.106·65, Rs.112·73, and Rs.72·09 per foot run respectively. The cost of boring the tunnel at shaft No. 2 was generally higher than at the north end; but at that shaft the machinery was not efficient.

The average daily progress in 1892 was a little over 4 feet; the average length in 1893 was 5·2 feet. In March, April and May, 1893, the machinery was stopped and work was continued by hand. From the 1st July, 1893, pumping operations were on a considerable scale, and one quarter of the firewood consumed after that date was properly chargeable to pumping.

The cost of erecting the machinery has been omitted, the Author being unable to arrive at the amount, as well as the influence on the general cost of the sum spent on the coolie camp. The value of the machinery and tramway plant has also been left out of consideration.

This Paper is accompanied by seven tracings, from which the *Figs.* in the text have been prepared.

Discussion.

Mr. J. WOLFE BARRY, C.B., President, said the members would recognize in the work, the description of which they had listened to with so much interest, one of very great importance, which had been carried out under many difficulties, not only from the undertaking itself, but from the inaccessibility of its site. They could scarcely realize in England how much the large works in India had added to them in anxiety and trouble by the difficulties of the climate and by the shortness of the seasons during which the operations had to be carried out. They must all recognize in the works described in the Paper the great care in the calculations, the tenacity of purpose, the resourcefulness of those employed, and the devotion which the staff must have shown in carrying out the undertaking under such difficulties. They would all congratulate the Author on the successful completion of his great enterprise, and also the staff, whose services he had acknowledged in terms so graceful and fitting. He begged to propose a hearty vote of thanks to the Author for his interesting Paper.

Lieutenant-General Sir RICHARD SANKEY, R.E., remarked that while he had held the position of Chief Engineer and Secretary in the Public Works Department to the Madras Government, between 1878 and 1883, it had been generally assumed that the Periyar scheme should be carried out as an earthen dam of gigantic dimensions, 200 feet in height. To European engineers this would necessarily seem preposterous, as it certainly did to the Author and himself. It had, therefore, been decided that the principle of the work should be that of the latest section adopted by the French engineers; and the dam ultimately took the form which had been carried out in all its details with such remarkable energy and success, that it had been recognized in every direction as one of the greatest works of its kind in the century. The work certainly merited great consideration, since throughout Southern India the country was, and always had been, threatened with famine. In the central and southern portions of the peninsula dependence had from time immemorial been placed to a great extent upon rain-fed tanks—a system of irrigation followed by the natives with wonderful success and energy. In the province to which he had been at one time attached (Mysore), there were thirty-seven thousand of those reservoirs, the largest of which had a surface of 14 square miles. In the Madras Presidency there were about

Sir Richard forty-two thousand. Such a vast system, or anything comparable to it, did not exist in any other part of the world. Nearly all the rivers and tributaries were, almost from their sources to a certain point, stopped by a succession of earthen banks. One such series in Mysore had no fewer than twelve hundred inter-dependent tanks. The natives had carried out the whole system, but in times of continued drought, particularly when dry seasons followed each other, the country was left with little if any assistance from water, depending entirely upon the tanks, which, being rain-fed, often dried up and failed. That had actually been the case in 1877-8, when there had been a probably more severe, though more localized, famine than the present one. When the engineers first went to India, one of the first duties devolving upon them was to systematize the plan of utilizing all the lower reaches forming the deltaic portions of the different rivers as they debouched on the eastern coast, so as to have the means of using for irrigation the perennial water of the different streams having their origin in the Western Ghats. That carried out by the Author was probably the last in succession of these great works along the eastern coast. Differing materially in design from the deltaic works to the north, it still would have the effect of affording a perennial supply which would be uninfluenced by anything affecting the general country in times of drought, and of insuring that the whole tract should have the means of irrigation. The great triumph of this work consequently was that it dealt directly and satisfactorily with the question of famine. The actual area that had the means of irrigation throughout India was generally calculated at about 30,000,000 acres. Of that amount 7,900,000 acres were due to works carried out by the Indian Government, at a cost of about 33 millions sterling, each work in all the great Presidencies having been originated with a view to counteraction of famine. There was hardly a single work, whether the great Ganges Canal, the Sutlej Canal, or the great deltaic works in Madras, that had not been called forth by that cause. In regard to the Madras Presidency, of the 5,000,000 acres under irrigation, nearly one half had been created by State money appropriated with that object. There were the great delta of works of the Godaverry, Kistna, Pennair, Tanjore, and lastly that described in the Paper. The works to which he had referred, were due originally to the genius, courage and skill of Sir Arthur Cotton; and the one under discussion had been carried out by the Author in an equally admirable manner. In regard to the expense, he found the dam had cost £175,000, to which must be added £47,000 for

what might be called headworks, the cutting and discharge tunnel, Sir Richard etc. The contents of the lake above the sill level of the outlet were about 13,000 million cubic feet. He gathered from the Paper that the reservoir would fill two or three times a year, so that a total of about 30,000 million cubic feet of water would be intercepted. Accepting the first figure, he found that the cost of the dam would be about 3*d.* per 1,000 cubic feet stored. Adding the cost of the cutting, etc., this amount would be increased to something less than 4*d.*, but, assuming 30,000 million cubic feet to be actually intercepted, the cost would not be much greater than 1½*d.* per 1,000 cubic feet stored. No doubt the Author would be able to give figures showing the cost in similar circumstances elsewhere in relation to the storage. Respecting the great Furens dam, he had not sufficient information on this point, but that of "la Terrasse," which cost £170,000, was calculated to intercept 150,000,000 cubic feet only for a height of 147 feet. The great dam at Lake Fife, near Poona, in Bombay, 97 feet high, cost nearly the same as the Periyar dam. The whole work cost about £625,000, including head and distributing works. In that case the area was about 5½ miles as against 12 miles of water spread over the Periyar dam. In regard to the conditions under which the work under discussion had been carried out, the Author had stated that there were practically five months only during which it could proceed, and this in broken periods. Fevers prevalent in that part of the country and along the west coast of India generally formed a serious obstacle to engineering work. In regard to one work which he had commenced at Mysore, an enormous amount of a then well-known fever specific called "Warburgh's drops" had to be procured in order to counteract the fever. Arrangements had also on another occasion to be made for taking the coolies by carts to and from the works daily. He quite agreed as to the desirability of having a removable shutter, or similar means, at the discharge outlet, to uphold, when required, a higher level of water.

MR. GEORGE FARREN was glad to see upon the walls of the Mr. Farren. Institution the representation of a rational dam (*Fig. 2, p. 143.*). He had heard it said in that room that such dams were not reliable; but he had carefully examined the one described in the Paper, and had found it very nearly what a scientific dam should be. He had on a previous occasion directed attention to the Chartrain dam, and had compared it with a theoretical one.¹ It was

¹ Minutes of Proceedings Inst. C.E., vol. cxxvi. pp. 95–98.

Mr. Farren. satisfactory to find that a dam of that character had been made by an English engineer, and he believed it was the only one that could be called a rational dam in the whole of the British Empire.

Mr. Hill. Mr. E. P. HILL appreciated the magnitude of the difficulties that had been overcome in the execution of the works, and could divine no reason for the prohibition to use a discharge tunnel, unless it were a supposed difficulty in closing at that depth after the dam was finished. In Great Britain the first step in the construction of a reservoir was the discharge tunnel ; he therefore asked why in this case that course had been prohibited ? The jets of water found spouting up in the foundation before the dam was built, were, he supposed, under the pressure of the water behind the temporary dams. Their height was between 2 feet and 6 feet, under a pressure of about 26 feet. The fissures had no doubt been plugged successfully ; but he wondered whether, when the reservoir was filled, and they were under a pressure six or seven times as great as that under which they were plugged, the plugging would be quite effectual ; and even whether other fissures under that pressure might not have shown themselves. In the case of the Thirlmere dam, all the fissures that could be found had been cut out, in order that there might be no water-pressure under the base of the dam when the reservoir was filled. Apparently in the present case this had not been thought necessary. He asked what was the specific gravity of the dam, the normal temperature at which it had been constructed, and the range of temperature to which it was now exposed ?

Mr. Vernon-Harcourt. Mr. L. F. VERNON-HARCOURT agreed that the form of the Periyar dam was very like that of the Furens dam, which might be called a rational section, except that in the latter a continuous curve formed the outer face, making the width of the dam increase more rapidly towards the base ; whereas in the Periyar dam there were two straight lines at an angle, in place of the curve, giving apparently the same kind of section as the Furens dam, though slightly narrower at the base for a similar height. The exact section, however, adopted for a reservoir dam of a definite height, depended upon the maximum pressure to which it was considered the masonry or concrete might safely be subjected ; for if a greater pressure than the maximum in the Furens dam, of about 6 tons per square foot, was admissible, then the section could be given a proportionately smaller width. The great water-pressure on these high dams was liable to cause leakage through them, unless the masonry was very compact or the inner face was coated with some impervious materials. No information appeared to have been given

in the Paper with regard to the watertightness of the dam. Mr. Vernon-Harcourt. Even more interesting, however, than the question of the dam, was that of supplying water for the crops at certain seasons to places deficient in rainfall. In India the nature of the country was extremely arid in the dry season, showing how very important it was to study the meteorology of each district, and to preserve all the water from whatever perennial streams might be available to bring it on to the land. As he had seen in 1896 at Calcutta, the meteorological observations were numerous in Bengal and were recorded in a series of diagrams in a very perfect manner. The variation in the amount of rainfall from year to year was remarkable. In the case of the basin of the Bhagirathi, which he had had incidentally to investigate, in 1895, the rainfall over that limited area was 38 inches in the year, according to the return in Calcutta —taking the average, and probably quite as little or less in 1896; whereas sometimes in that same district it increased to 64 inches or 65 inches. Famines appeared to occur in India mainly after two successive seasons of small rainfall, as in 1877 and at the present time; and irrigation works from perennial rivers offered the best means of mitigating such calamities. There were also much greater variations of rainfall in India according to the locality. In some places the rainfall might not be more than 2 inches or 3 inches, as at the hill station of Leh, while at Cherra Poonjee in Assam, for instance, the average was about 474 inches in a year, which he believed was the highest recorded rainfall in the world. He had no knowledge of Southern India, but it was with great interest that he had learnt from the Paper that, owing to the rainfall being greater on the west coast than on the east, it had been possible to bring some of the excess of the Travancore rainfall on the western side of the ridge of hills into the Madura district on the eastern side, where there was a great deficiency. The Paper was of great interest, especially in connection with the difficulties that had occurred, and the way in which they had been overcome, as well as the fine dam that had been constructed to store up the rainfall, and the tunnel made to convey it through the dividing ridge into the eastern river basin. It was obvious that such works could not be carried out without knowledge of the meteorology of the district. He had been much interested in observing the limited times during which the work could be carried out. In respect of its floods, the River Periyar differed from the rivers of North Eastern India, where the Ganges rose fairly continuously at the head of its delta, beginning slowly about May, and reaching its maximum in September, and then gradually falling. In the Periyar basin there appeared to be

Mr. Vernon-Harcourt. a cessation of floods generally in September and October, and then a recurrence of them; but evidently complete freedom from floods in the interval, in the autumn, could not be relied upon in that rainy district, near the head of the basin. It was necessary to study carefully the meteorology of the district to obtain a knowledge of what work could be done for irrigation, and the periods at which it could be carried out. The two things clearly went together, and the way in which the work had been carried out reflected great credit upon all concerned in it.

Mr. Symons. Mr. G. J. SYMONS suggested the desirability of an index-map to show the positions of the places described in the Paper. With regard to the subject of rainfall, he had the highest appreciation of the magnificent way in which the meteorology of India¹ was being worked. The subject of compensation had not been referred to by the Author. If a stream in England from one watershed had been led through the hills and discharged into another, the original owners would have something to say about it. He was surprised to find the Madura district described as "one of scanty rainfall." The average rainfall in the Madura district was 28 inches, the driest station having an average of 18 inches, and the wettest of about 37 inches, Madura itself having about 33 inches. It certainly was not dry, compared with Kurrachee and portions of North Western India. On a previous occasion² Mr. T. Sopwith, Jun., had given interesting details of the temperature of the face of the Mont Cenis tunnel after it had been left a considerable time, so that the effect of blasting and the like had passed away. The results of observations of a similar kind made in regard to the tunnel described in the Paper would be interesting. It appeared that owing to climatic conditions the work was generally suspended three or four months, so that any effect of drilling or blasting, which would have heated the rock, would have had ample time to pass away before the renewal of the work. The general scheme appeared to be an illustration of the great advantage to India of English rule.

Mr. Deacon. Mr. G. F. DEACON observed that the Author had adopted a form of dam which was no doubt perfectly satisfactory and stable if well constructed, as he had no reason to doubt it was; but it behoved engineers to take note of any matters which might appear even on the surface to be otherwise than the best possible practice. He thought the great difference which was apparent from *Fig. 2*,

¹ Indian Meteorological Memoirs, Calcutta, 1876, &c.

² Minutes of Proceedings Inst. C. E., vol. xxxvi., p. 4.

p. 143, between the rubble and the concrete, did not exist in practice. It might be that the moduluses of elasticity of the two were much less different than would appear when they were placed in juxtaposition with such different shading as that shown in the *Fig.* He did, however, think that the construction of straight-faced walls on the inner face of a dam, against which concrete was subsequently to be placed, was a mistake. There was undoubtedly sheering stress over those long, deep surfaces, and it was certainly desirable to avoid change of structure at planes along which such stress occurred. The next point that struck him as singular was the abandonment of the cutting to the rock on the saddle at the left flank, and the continuation of the dam by means of earthwork not carried down to the rock. The fierce light that shone upon the engineer in England would probably make so bold a course impossible without the risk of serious criticism; but, all things considered, he had no doubt that it was a right thing to do, and it had turned out successfully. He did not, however, understand why this little dam was half of masonry and half of earthwork, with a straight joint down the centre. No doubt the two were properly tied together, but he should be glad to hear why the earth dam was not carried across the full length of the little valley. In test-blocks subjected to compression the depth in relation to the breadth and width was a very important matter. He therefore asked what was the thickness of the test-blocks of concrete which had given such excellent results? To secure uniformity of practice it was desirable to use cubes or cylinders of depth equal to the diameter. If the 80 tons per square foot mentioned at p. 157 as the ultimate strength of blocks, six months old, was obtained from cubes representing the concrete exactly as it was used in the dam, the result was very satisfactory, and was a further justification of the opinion he had often stated and practised—that, except where running water could not be avoided before the lime had set sufficiently to resist it, good hydraulic lime, or, what was in effect the same thing, rich lime and pozzuolana, might, if properly manipulated, be used instead of Portland cement with great advantage and economy.

Mr. W. H. HALL observed that the escape-way or waste-way was simply a cutting through rock without any weir or structure upon it. The top of the dam was intended to be 11 feet above the bottom of the escape-weir, and the full flood-water was expected to rise 9 feet of that height. With regard to the areas given for full water at the level of the bottom of the weir, and the 9 feet

Mr. Hall increased depth, the storage capacity produced there of 2,716.5 million cubic feet¹ (compared with 6,815 million cubic feet which the reservoir stored from the level of the outlet-cutting up to the level of the overflow weir) was nearly 50 per cent. of the effective storage. A structure was thus provided which would really retain nearly 50 per cent. more than the effective storage and lose it again. It had occurred to him whether lowering the cutting by taking out more rock to construct the dam, for the rock for its construction had to be hauled a long distance, and providing a movable dam in the cutting, would not have been cheaper, and at the same time have admitted of lowering the main dam between 4 feet and 6 feet. It appeared that the dam was 4 feet or 6 feet higher than was necessary to provide for storage. A movable dam in the escape-way would have held the water up to within, say, two-thirds of the depth of the 9-foot prism which was now to be wasted. In the United States Geological Survey—which had carried out a few years ago an extensive investigation as to the storage of water in the United States—four hundred reservoir sites had been surveyed. Plans for the dams were made for most of them—standard plans for different kinds of dam—and applied for the study of the storage of water in different classes of sites. He had had the honour of acting as Supervising Engineer on that branch of the survey. The advantage of providing a movable weir or dam in the escape-way to reduce the height of the dam when necessary was always observed. The amount of storage-space estimated to be necessary was 7,000 million cubic feet; but the storage-space actually available between the sill of the outlet and that of the overflow was 6,815 million cubic feet. It was also stated that the intention had been to provide a minimum constant flow of 500 cubic feet per second;² and the width of the overflow cutting was 21 feet. He estimated that to produce that flow of 500 cubic feet per second the depth in the cutting would have to be nearly 6 feet, and possibly more, according to the roughness of the sides. He considered that the 3 feet of depth necessary at the reservoir to produce the minimum amount of outflow, was not available for the irrigation purpose, for, in drawing down the water, as soon as the 3 feet of depth was reached the minimum flow was not obtained, and consequently that minimum depth must be omitted

¹ For the expression of such volumes of water the unit "acre-foot" was employed in America. It denoted the volume of water covering an area of 1 acre to a depth of 1 foot.

² The velocity of 1 cubic foot per second was in America designated the "second-foot."

from the available or efficient capacity of the reservoir. He Mr. Hall. estimated that 3 feet of depth to give about 500 million cubic feet, so that only 6,315 cubic feet remained. He did not see in the Paper any mention of loss by evaporation, which assuredly must be great. In America a minimum loss was estimated of 2 feet in a season between the time the reservoir filled and when the water had to be used, and from that up to 4 feet. He considered 3 feet would not be an over-estimate in the case in question. Taking 3 feet as the amount and applying it to the mean of the full-water and the low-water areas—the loss would be 664 million cubic feet. The total was thus diminished to 5,650½ million cubic feet, or about 20 per cent. less than was said to be required. He also observed that the cutting had no gradient for the first 3,000 feet, beyond which it was 1 in 320. To produce in the upper end of the cutting a flow which the lower end would take, there must be an equivalent hydraulic gradient. If that were applied, a little more than 9 feet was taken off the available prism in order to get the water to flow through, so that the amount was reduced by 1,568 million cubic feet, leaving only 4,082 million cubic feet. In order to produce the minimum flow of 500 million cubic feet a second, as soon as the water arrived at that level, the minimum flow would be reduced, else there must be a greater water-way in the upper 3,000 feet of the escape. It seemed, from the figures given, there must be a deficiency of storage below the 7,000 million cubic feet, which were said to be necessary, of as much as 2,000 million cubic feet, or nearly one-third. It would be exceedingly interesting to know why that was. The decision of the professional advisers of the Government for India not to allow the tunnels round the end of the dam, to carry the water away during construction, would in America be considered a very curious ruling. If there were a tunnel round the end of the dam it would be a great convenience when it was desirable to empty the reservoir altogether; in America such provision was always made. It would also have immensely diminished the cost of construction. The point mentioned by Mr. Deacon of the apparent lack of unity between the rubble-construction and the concrete, had also struck him. The back of the front wall appeared to be quite smooth and well worked like the front. In that case there could not be any junction between the two materials; and should there be a leak at any point—especially from a very slight motion due to the difference of temperature, or to the varying pressures at different times—so as to start the smallest rupture between the types of construction,

Mr. Hall. there might be a leak through the front wall, there would be hydrostatic pressure, which, in the course of time, might be harmful. He might call attention to the Croton dam,¹ one of the old dams of the New York water-supply, which had been built of concrete with a kind of ashlar facing. The greatest pains had been taken in the construction of that dam to bring the ashlar work and concrete together. Never more than one layer of ashlar was applied before the concrete was brought up; there were alternate layers, with mortar let in to make a good bond; and, as in laying bricks, they were all lapped close together. If the rubble portion had been omitted, and all of the subsidiary dam had been made of earth, the latter would have a better junction with the bed-rock at the right-hand side of the saddle than it could possibly have at the end of the dam to which it was joined. At present, the earth abutted apparently against the vertical wall of masonry; he had known of several failures from that cause. In one case the earth-work embankment or dam had been placed against a nearly perpendicular face of basalt rock, and during one season it was not filled with water. Notwithstanding that it was built in the most careful manner, and was rammed in as much as possible, the earth shrank away from the basalt, and pebbles and gravel-stones could be inserted in the joint before the end of the season. When the water had been let in again, it broke through, and in that way a catastrophe had been prevented.

Mr. Binnie. Mr. ALEX. R. BINNIE thought the Paper described a work carried out under very peculiar difficulties, which few could experience who had not had to work under the tropical conditions described. These rendered it almost impossible to proceed for several months in the year owing to the unhealthiness of the climate; and at other times, owing to the floods, it was impossible to carry on any engineering work, so that only a very small portion of the year in each season was available for active operations. The difficulties of the site were sufficient to discourage any engineer from undertaking a work of that description, and they were added to by the peculiar dictum of the Government in India. He knew what that Government was; it issued its fiats, but did not give its reasons. In the present case, as in many others, the mystery was inscrutable why so very peculiar a handicap was placed upon the engineers who had to construct the work. The work, however, had been completed, and it would carry with it to all time the impress of that peculiar, and, in his opinion, erroneous, judgment.

¹ Transactions of the American Society of Civil Engineers, vol. iii. p. 837.

What was to happen should it ever become necessary to empty the Mr. Binnie reservoir he did not know, short of blasting a tunnel, which ought to have been constructed in the first instance. He could not, however, help thinking the Paper was deficient in many important points. Dealing, as it did, with so important a subject as the irrigation of a district like that of Madura, which was historically dry—the drought from which it always suffered having been, by means of the works described, brought within the compass of engineering skill to overcome—it was almost a pity that the Paper did not describe how it was done. The water must come from somewhere. Where? What was the drainage area? What was the rainfall on that area? What was the average flow of the river? and what was the minimum flow? The difficulties arising from the floods had been carefully pointed out by the Author, but the whole design depended on the sources from which water was obtained. To attempt to criticize the storage provided by the dam, was futile without knowing the amount of water available to place behind that storage, the perennial stream which came down the river, and how much of it could be depended upon in the driest seasons. The case was unique, even in India, in which an engineer had to deal with a perennial stream subject to such great vicissitudes of flood and drought. It would be interesting to have a record of all the great facts on which the work was based.

Mr. F. J. WARING noticed that the sill of the watershed cutting Mr. Waring. was 113 feet above datum, whereas the bottom of the dam was at the datum level; there were therefore 113 feet of the depth of the reservoir unavailable for irrigation. It was also stated that the contents between these levels amounted to 6,484 million cubic feet, or nearly one half of the total contents impounded. It appeared therefore somewhat strange that the dam had been built so far down the stream. If the site of the dam were chosen higher up the stream, where its bed was at the level of the watershed cutting, the height of the dam would naturally have been much smaller, and it would have been a much less difficult work to execute; no doubt there was a sufficient reason for the present site of the dam, but it was not disclosed in the Paper, and he trusted the Author would give information on the point. From the second Paper, he observed that the ground on which the cutting was made was nearly level, therefore to have lowered the tunnel 113 feet would have vastly increased the work. At a place in Ceylon, near Pattipola on the Haputla Railway, the Cingalese had carried out a similar work upon a small scale, and had diverted

Mr. Waring. a stream which flowed into the district of Dimbula, where the wet season was in June and July in the south-west monsoon, to Uva, where the wet season was in October and November in the north-east monsoon, so that the Uva paddy fields below the stream derived the benefit of both monsoons. The ground above the tunnel through the watershed was in this case only about 40 feet in height; the tunnel itself was 120 feet long. It was unlined and passed through compact and hard earth. Although the tunnel was so short it had been excavated by two or three shafts or else the crown had fallen in at two or three places. He had been unable to ascertain when this work had been executed; but the spoil banks were covered with trees of the same kind as the adjacent forest, showing that they must have been deposited a great many years ago.

Mr. Chatterton. Mr. A. CHATTERTON believed the area under irrigation was about 100,000 acres in the Madura district, so that the total capital cost did not amount to more than £5 per acre. With so large a work, in which the dam itself contained 6,000,000 cubic feet of masonry, costing Rs.3,000,000, or roughly 7½d. per cubic foot, the low cost, under the difficult circumstances described in the Paper, was largely due to the excellent arrangements at the outset for carrying on the work, and the exhaustive and complete surveys made nearly thirty years ago. Such projects in India generally required a long time to mature, and the same individual seldom began the preliminary investigation and carried the whole work to its conclusion. It was no doubt due to the circumstance, that throughout the whole project there had been one mind guiding and controlling, that it had been carried out at such a comparatively small expense. The action of the Government of India in regard to diverting the water through tunnels round the flanks of the dam, appeared all the more curious since about the same time in the Bombay Presidency a dam had been constructed at Bhatgarh for supplying the Nira canal in which the technical advisers of the Government had allowed a totally different course to be pursued. Particulars of it had been given in the discussion on "Impounding Reservoirs"¹ which took place about three years ago. The dam was 103 feet high, and therefore, although it was not so large as that under discussion, it was a considerable masonry work. In its construction not only were fifteen sluices, each 8 feet high and 4 feet wide,

¹ Minutes of Proceedings Inst. C.E., vol. cxv. pp. 159 and 166.

permanently provided for the discharge of the water during the Mr. Chatter-flood season, but permission had been given to make a tunnel ^{ton.} (the height of which was not stated, but the width was 6 feet) through the dam solely for the purpose of obtaining water for washing sand. If some such course had been pursued in connection with the Periyar dam, the difficulties connected with its construction, especially in the earlier stages, would have been greatly lessened. The diversion of the Periyar River had afforded a source of water-power which, in all but magnitude, was probably unequalled in the world; apparently 60,000 HP. could be developed without difficulty. The question of the successful utilization of the power seemed to depend upon finding means for using it. If the water-power was to be used as a source of revenue, and an amount equal to the returns from the irrigation were to be levied as a charge for it, it was evident that about £35,000 a year would have to be paid for the 60,000 HP. available. Under ordinary circumstances in England, to obtain 60,000 HP. for £35,000 a year would be a good bargain, but it was doubtful whether the water-power in such a locality as the outlet from the Periyar Tunnel, and subject to such a heavy first charge, would be of great value. The question of utilizing water-power had been discussed in Madras during the last few years, and it had been regarded as a possible means of developing the great mineral wealth in the Presidency. It seemed probable that the water-power of the Periyar project might be conveniently used for metallurgical purposes. It was doubtful, at any rate, for a long time to come, whether the development of electrical power at the foot of the ghat, and its transmission to the town of Trichinopoly and possibly Madras, could be carried out. Indian towns were generally comparatively poor, and scarcely likely to be able to afford expensive electrical works. Although electric lighting was possibly a great advantage, the people were not able to pay for it, even if it could be supplied at the rates which might be obtained with a cheap supply of power. In the immediate future, therefore, the only possible prospect of utilizing that large amount of power was its employment for metallurgical purposes. A large amount of power could thus be absorbed in a comparatively limited space, and he believed the Government of India were carrying out investigations as to the natural resources of the districts round Periyar, with the view of ascertaining whether there was material which could be worked by electro-metallurgical methods. If any such scheme were carried out, a charge of Rs.10 or Rs.12 per HP. per annum would

Mr. Chatterton probably be a serious expense to be incurred by what must be regarded as a pioneer undertaking, and for that reason he thought it was hardly likely that, for some time to come, any considerable revenue would be derived from the Periyar project by the utilization of the water-power at present available.

Professor Unwin. Professor W. C. UNWIN regarded the work described in the Paper as an achievement in which the difficulties were not only of an engineering character, but of a kind to test the pertinacity and endurance of the engineer, and his moral courage. He wished to offer a protest against the suggestion to call 1 cubic foot per second a "second-foot." In a number of cases a unit which was the product of two simpler quantities was employed, and in those cases a hyphenated name was adopted. The product of feet and pounds was called a foot-pound, and the product of degrees and pounds was called a pound-degree, and so on. But in England a little respect was still paid to some conventions; and he did not quite see why feet divided by seconds should be called a "second-foot." The first important point about the Author's work was the composite character of the dam. The second point to which he might refer was the question whether, in a narrow V-shaped valley like that of the Periyar, it would not have been better to build the dam with a curved plan. He did not say that method was certainly better, but he thought it was exactly the case in which a curved plan would have been considered. With regard to the possibility of utilizing the great water-power which poured down on the Madras side of the hills, if there were only some use to which to apply it, great value would be added to the work. It could be developed with less difficulty than in many other places. The fact that no storage or regulation was wanted had been referred to by the Author. There were cases in which water-power had been used and a large expenditure incurred, especially in storage, which had to be constructed in order to make the supply constant and to be worth utilizing. Those, however, were cases where there was a poor water-power in the neighbourhood of a great population, and where the value of the power was so great that the expenditure on storage-works was justifiable. It was an exaggeration to say there was no other water-power so good in the world. He had had to survey one source of power in America with a view of utilizing 250,000 HP., where certainly the difficulties of utilization were even less than at the Periyar. He imagined also, that there were, if they were looked for, many other such positions, and it was not necessary to travel as far as the hills at Periyar to find sources of water-power

which could be utilized very cheaply indeed. He believed they were being utilized to greater extent than English engineers were generally aware of, and the reason why they were not more utilized was the extraordinary expensiveness of the electrical engineer. The moment distant transmission became necessary and the electrical engineer came on the ground, the price of the power increased considerably. At Niagara the price at which the power could be sold had to be carefully investigated when arrangements were being made to supply the City of Buffalo, 20 miles distant. It had been offered to supply the power undeveloped—that was, to yield the water-rights, the use of the head-races and tunnels, the expensive hydraulic part of the work, for a charge of \$10 per HP. per annum, the HP. being supplied twenty-four hours in the day. Further, it would be supplied developed and delivered from the turbine shaft at \$13, reckoning that the hydraulic machinery that would be necessary would add to the price \$3 per HP. per annum; and it was offered at Niagara, in the shape of electricity at 2,000 volts, at a price of \$18 or \$20. Contracts had been made for \$20, and, in case of Buffalo taking a large supply, \$18. He did not know the charge to be made at Buffalo, but the Company had absolutely resisted being tied down to any price at Buffalo, or to supply there, except in open competition with steam power, which cost, with well arranged and economical plants, \$60 per HP. per annum for a twenty-four day. The increase was due to the cost of transmission.

Colonel PENNYCUICK, in reply, thanked the members for the kind way in which his Paper had been received. He believed the temperature fluctuated between 50° and 90° F.; the normal was probably between 75° and 80°. The specific gravity of the masonry was about 2·30, or 145 lbs. per cubic foot. Judging from the amounts of material used, the weight of the masonry was not much greater than that of the concrete. The concrete was well rammed, and contained a small quantity of mortar carefully mixed, and he did not think the masonry weighed more than 150 lbs. per cubic foot. Reference had been made to the small fissures in the bed of the river when it was laid bare. They could hardly be called fissures, for they were little more than capillary tubes, tiny spouts rising to 2 feet or 3 feet. To have cut them out or to have provided for them by drains would have been of doubtful utility, and would have certainly taken a great deal more time than they were worth. They were choked without the slightest difficulty, and he had no doubt that long ago they had been filled by the earth and material brought

Colonel
Pennycuick.

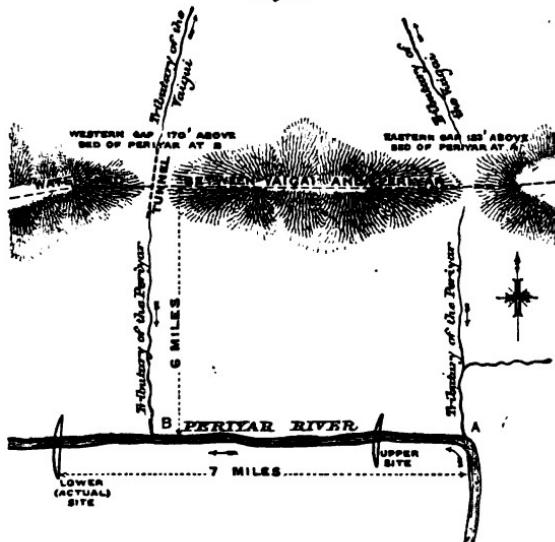
Colonel Pennycuick. into them by the force of the water. At all events they had not given trouble, and he did not anticipate any. He had not the slightest idea what were the reasons that had led the Government of India to prohibit the tunnel through the dam. One object among others for using a tunnel was to provide for the possibility of having to unwater the lake hereafter. That, however, was prohibited, and he had to do the best he could without it. There was no Congress to go to in India. Its Government was a very autocratic body. "*Sic volo, sic jubeo,*" was all it had to say. Choice had to be made between dropping the work altogether and carrying it out as the Government insisted, and he thought most engineers who took a pride in their profession would say that those who had the work in hand were right in doing the best they could to carry it through. He entirely agreed as to the importance of meteorological observations; not only the nature of the work itself, but the whole of the proceedings from beginning to end, were absolutely ruled by such considerations. For some years before the work had begun, and during the whole time of its continuance, careful observations of the rainfall had been made twice daily at two stations in the area of the lake, and those records had been carefully consulted before any steps were taken for raising the water-level, or closing a vent, or any other purpose. He did not think accurate records of the temperature had been taken in the tunnel; it was not considered a matter of great interest, the conditions of the tunnel being totally different from those of the Alpine tunnels. The greatest distance from the sill of the tunnel to the surface of the ground above was never more than about 200 feet, and the variation of temperature could hardly be a matter of importance. It had been observed that the slope of the rear face of the dam consisted of a series of straight lines in place of the curve which a theoretical section would give. It was only in the lower part of the dam that the theoretical section would be an unbroken curve. In the upper part the points to be chiefly considered were the absence of tension in the front face of the masonry and resistance to over-turning and sliding. A simple triangular section was really the theoretical one for these three considerations, and the curve, due to the resistance to crushing, only came into play in the lower part of the dam. With a dam of that height, for the first 40 feet or 50 feet it was a very flat curve, and practically the section, as given, *Fig. 2, p. 143*, did not differ anywhere by a foot from the theoretical section. The amount of compensation had been fixed at Rs.40,000 a year for the right to take the water, and the negotiations leading to it had been long and troublesome.

In India the Acquisition of Land Act saved a great deal of trouble to which English engineers were subject; but unfortunately land could not be taken under that Act because Travancore was an independent State, and the matter had therefore been the subject of negotiation. With regard to the material of the dam, the mixture of rubble and concrete, the arrangement of the rubble was much more uneven than appeared from *Fig. 2, p. 143.* It was not really a series of straight lines, either horizontal or vertical, but was joggled and left uneven in every way. He did not, however, attach great importance to the difference of consistency between the rubble and the concrete. They were nearly the same material, and he did not believe there was appreciable inequality of settlement. There was nothing to be feared in regard to the two materials separating from each other. He agreed that for many reasons it would be desirable to have a movable dam on the escape. It would certainly give increased storage and save a certain amount in the construction of the dam, but after thirty years' experience in public works in India he did not believe in any work of importance being allowed to depend upon apparatus that required to be worked at the right time by native subordinates. If it was desired to prevent a dam being topped (whether of masonry or earthwork) the apparatus should be absolutely automatic. In many tanks in the Madras Presidency there were what were called dam-stones on the weirs, the intention being that they were packed up with sods and turfs to raise the water above the level of the sill of the weir in dry weather. At the approach of the monsoon they were supposed to be cleared to allow the flood-water to escape, but they were never cleared by any chance, and he believed he was within the mark in saying that two-thirds of the breaches of tanks in South India had arisen through the existence of those dam-stones. In every instance where he had the power to do so he had had them removed. He would rather spend a little more money in securing absolute safety than save expense at the risk of the whole structure. With regard to the quantity of storage necessary he had said in the Paper that it was about 7,000 millions; the actual storage was 6,815 millions, and included the whole of the losses to which Mr. Hall had referred. It included the quantity necessary to produce the flow through the cutting, and all the loss by evaporation, which was enormous. The latter had been taken, not at 3 feet, but at $7\frac{1}{2}$ feet per annum. Since the beginning of the work, careful records of the discharge of the river had been taken month by month, and he had kept a record showing what the state of the reservoir would be, supposing it had

Colonel Pennycuick. been completed in April 1889 and irrigation had been going on from it, the supply coming month by month ; and allowing for the loss by evaporation, not only from the lake itself, but also in the passage to Madura, as well as the amount drawn off for irrigation, the result showed that with a full supply used for irrigation the water in the lake would never, except for a few weeks in 1894, one of the driest years on record, have fallen below about 125 feet above datum, or about 12 feet on the cutting. As to the depth required to give discharge through the cutting, although there was next to no fall the first 2,000 feet or 3,000 feet, the greater part of it was in earth and it was very wide, being, in fact, more an arm of the lake than a cutting. He entirely agreed that an earth-bank across the saddle on the left bank would have been preferable, and had he known all the physical facts at the time the work was begun he should have adopted that course, but it then appeared that the rock was as shown in the right-hand part of the section of the saddle, *Fig. 1*, p. 142, and it was not until later that a fault was discovered towards the left flank, and then there was not time to make any alteration. A whole season would have been lost in attempting to construct an earthen dam. A good deal of masonry had been completed and the best had to be made of what at the time appeared a difficulty. He was bound, however, to say that the result was perfectly safe. He had acted with a full knowledge of the conditions, and there had not been the slightest sign of slipping in the bank since its completion. He could imagine no more insane plan than attempting to make an earthen bank abut against the back of a flat masonry wall. The wing-wall shown in *Fig. 5* was stepped ; it had buttresses every 10 feet and there was not a flat joint 6 feet square between that and the earth from one end to the other ; there was no puddle. In India very little puddle was used ; the way in which the earthwork was carried out practically made puddle of the whole thing. The material was not tipped from a large wagon, but it was carried in small baskets and trodden by the feet of the workmen ; and unless the soil was very bad indeed (which it was not there) puddle was not necessary. The test-blocks referred to by Mr. Deacon were cubes. The criticisms of Mr. Binnie were directed rather to the Paper itself than to the works which it described. No doubt there were many points of interest that might have been discussed in more detail, but it was by no means easy to make a selection in this respect, and to have discussed fully every point connected with a work of this class would require, not a Paper, but a volume. The

Paper was not, however, quite so deficient as Mr. Binnie implied, Colonel the average and minimum discharge of the river being stated. Pennycuick. The drainage-area was 305 square miles and the average rainfall was, he believed, about 90 inches per annum. The discharge of the river for the ten years during which records had been taken varied between 22,416 millions of cubic feet, representing 32 inches over the whole drainage-area in 1894 (a year of abnormal drought), and 54,640 millions of cubic feet, or 78 inches, in 1891, the average being a little over 50 inches. The ratio of the run-off to the rainfall would appear large, but a large

Fig. 1.



SKETCH MAP OF WATERSHED BETWEEN THE VAIGAI AND THE PERIYAR.

part of the drainage-area was occupied by steep hills with no great depth of soil overlying the rock, and there was reason to believe that the rainfall in the upper or southern portion of the basin, at present almost inaccessible, was greater than at the stations on the lake, where the rainfall-register had been kept. The sketch map, *Fig. 1*, would assist the reply to Mr. Waring's remarks as to the site chosen for the dam. The general direction of the River Periyar was from south to north, until about 7 miles above the site of the dam, when it turned abruptly to the left at right angles, and ran almost due west to about 1 mile below the dam, after which it turned

Colonel Pennycuick. slightly to the north again, and ran about west-north-west to the sea. During the 8 miles of its westerly course the river was within about 6 miles of the watershed ridge, and in this 8 miles were two remarkable depressions in the ridge which was everywhere else between 1,000 feet and 3,000 feet above the river-bed. At the most easterly of these depressions, which was due north of the great bend, the watershed ridge was 183 feet above the bed of the river; at the other, which was about north-north-east of the site of the dam, the difference of level was only 170 feet. Both depressions were at the head of tributary streams, which now formed arms of the lake. It was abundantly clear that it was only at one or other of these depressions that the watershed could be crossed without prohibitive expense in tunnelling, and that the dam should be as close as possible to the mouth of the tributary stream leading to the depression chosen for the passage. To the west of the upper tributary there were three good sites, of which the best was about $\frac{1}{2}$ mile below it, and this was the site at which it was originally proposed to construct the dam. Later investigations showed clearly the enormous advantages of the western depression, and for this the only practicable site was that actually chosen, which was about 1 mile below the mouth of the tributary stream, the fall of the river in this distance being about 3 feet. In the 6 miles between the two tributaries it rose 31 feet more, and in the 6 miles above the upper tributary it rose no less than 150 feet. The valley between the two sites was flat and open, and contained numerous wide tributary valleys, giving enormous advantages in the way of storage. How great these advantages were might be inferred from the fact that a dam 160 feet high at the lower site impounded more than double the quantity of water impounded by one 220 feet high at the upper site, while all the advantages of facility of access were on the side of the lower site. The propriety of placing the dam higher up the river had been considered, but it was shown conclusively that this course, in addition to sacrificing more than half the drainage-area of the river, would cost considerably more than that adopted, as the only way of crossing the watershed would be either by a tunnel at least 10 miles in length, or a contour channel, the cost of which would be even greater, while the cost and difficulty of maintenance would have been excessive. It might be mentioned, in proof of the advantages of the site actually chosen as regards the water impounded, that the Furens dam, which was almost exactly the same height, impounded 68 millions of cubic feet, or just one-hundredth of the available storage of the

Periyar dam, while the cost of the latter was less than £14 per Colonel Pennycuick million cubic feet of total storage, and £27 per million cubic feet of available storage. He knew of no dam which gave comparable figures. He thought Prof. Unwin had mistaken the deep chasm in the river-bed, mentioned in the Paper, and clearly shown in the section, for the river-bed itself. The latter was 200 feet wide at normal water-level, and over 300 feet at high flood-level. But it was the length at the top and not at the bottom which governed the possible radius of curvature of a dam, and this length was 1,300 feet. No conceivable radius of curvature would allow the section of the dam to be reduced without an addition to the length, which would far more than outweigh the saving by such reduction. He was sceptical as to any advantage to be gained from curvature as regards the effect of changes in temperature, which could be, and were, quite sufficiently met by the elasticity of the material used in this dam, whatever might be the case in the more rigid Portland cement generally used in England.

Correspondence.

Mr. FAIRLIE BRUCE considered the objections of the Indian Mr. Bruce. Government to a tunnel outlet, for the discharge of flood-water, quite inexplicable. A suitable tunnel could with ease have been constructed through the body of the dam at or near its base, and could afterwards have been plugged in the ordinary way. A permanent outlet sluice would also have been of great service in the event of its being necessary to empty the reservoir for repairs. The risk, apart from the question of convenience, of such an outlet would have been much less than with the method of disposing of flood-water described in the Paper. The manner adopted for dealing with springs appeared risky, as diminishing the resisting power of the dam, and for other reasons. If it was impossible to cut them out, the safer course would appear to have been to have drained them to the outer face. It would also appear that the dam was not connected to the rock either at the base or at the flanks, frictional resistances being solely relied upon. This was not in accord with usual practice. As the result had been successful, however, possibly the Author was justified in the course he had adopted. Corresponding particulars of the cost of tunnelling on the Blane Valley section of the Loch Katrine

Mr. Bruce. Aqueduct, in new red sandstone, were given in the following Table :—

MACHINE DRIVING.	Cost per Cubic Yard.
Labour (1·34 cubic yard to 0·95 cubic yard excavated) per day)	s. d.
Plant, horses, &c.	5 9
Explosives and light	1 9
	2 2
Total	9 8

HAND DRIVING.

Labour (0·76 cubic yard to 0·66 cubic yard excavated) per day)	7 9
Plant, &c.	1 6
Explosives and light	1 2
Total per cubic yard	10 5

The cross-sectional area of the tunnel was about $10\frac{1}{2}$ square yards.

Mr. Collignon. Mr. E. COLLIGNON, of Paris, admired the method of procedure adopted in the important works described in the Paper. The section of the dam appeared quite suitable, and the thicknesses sufficient to assure the general resistance of the work to the hydrostatic pressure. He regretted, however, the whole mass had not been constructed in masonry; much would thereby have been gained in homogeneity, durability and security. The courses might have been laid perpendicularly to the resultants of hydrostatic pressure and weight, to aid the equilibrium of the dam, which might have been constructed in plan of such form that the pressure of the water would tend to close the joints. The mass of masonry and of concrete was, on the contrary, exposed to disintegration under the action of unequal settlement, and the concrete was liable to become fissured in directions which could not be foreseen and which might act prejudicially as regards the preservation of the dam. The adoption of masonry for the whole of the work would not have necessitated a much greater outlay. The extreme thickness of the work was limited to the bottom portion, where the valley was very contracted, and where the space to be filled was consequently reduced to a short length, transversely to the valley. Again, the width of the dam at and near the crest was so reduced that it was little, if any, greater than the thickness of the two masonry facings.

Mr. J. GAUDARD, of Lausanne, remarked that although of Mr. Gaudard. smaller dimensions than that at Periyar, the dam at Verdon¹ had also given rise to difficulty, despite the tunnels pierced through the rocky hill-flanks for the diversion of the water. The season suitable for foundation-work was found to be limited to three or four months, when the water was at low level; and one year had been lost owing to unexpected floods. A thickness of 23 feet of gravel had to be excavated in order to form the foundation mass of concrete resting on the solid rock, and the leakages through the lower part of the cofferdam necessitated considerable pumping. The site was divided into three trenches by four lines of sheet-piling at right angles to the river. The excavation and the concreting were first carried out in the down-stream, then in the up-stream, and lastly in the central division. The dam was of masonry, 36 feet high, and formed a weir with a stability calculated to carry the overflow of a sheet of water 16·4 feet in thickness. It was curvilinear in plan, its ends being let into the rocky sides of the ravine. During its construction a temporary breach 16·5 feet wide had to be made near the end at the right bank to allow of a supplementary escape for the water. The semi-cylindrical wrought-iron caissons employed by the Author for stopping the flow of water through the vents, or orifices of discharge, arranged in the up-stream face-wall of the Periyar dam, recalled the method employed in repairing the quay-walls at St. Nazaire by a portable cofferdam placed with its open face against the face of the wall.² Being of timber the-coffers in that instance were not semi-cylindrical, but were formed by three adjacent planes, and did not extend from the top to the bottom, but could be placed in position at any desired height, the lower end being closed by a tapering base, and the vertical edges being provided with flanges for attachment. The cylindrical sluice of the tunnel discharge, *Figs. 6, p. 154*, situated in the main dam, setting free instantaneously a large effluent volume with the minimum expenditure of raising power, was analogous to the barrel-slusice applied by Mr. A. Fontaine to locks. In the Morailon type of cylindrical sluice it was not necessary to raise the movable cylinder above the level of the feed, but only to a fixed stop, surmounted by a narrower tube. With regard to the construction of the Periyar dam partly in rubble masonry and partly in concrete, at the Furens dam,

¹ *Annales des Ponts et Chaussées*, vol. iii., 1872, p. 428.

² *Ibid*, 1888, vol. xvi. p. 780.

Mr. Gaudard. St. Etienne, it had been considered important to make the masonry as homogeneous as possible of rubble masonry in hydraulic-lime mortar, without any ashlar work, so as to avoid the possibility of fissures arising from unequal settlement due to the ratio of the stone and mortar being altered wherever ashlar took the place of rubble. Small parallel internal walls cutting through the base of the concrete mass were shown in *Fig. 3*, p. 146, but their purpose was not explained. Were they adopted with a view to increasing the resistance to percolation? The maximum pressures on the materials, and the method by which the Author had calculated the section of equal resistance of this colossal wall were not stated in the Paper. The question had much exercised French engineers, many of whom had prepared sectional types.¹ In 1892 the "Société des Ingénieurs Civils" had published the section recommended for the Chartrain dam, as the result of the investigations of Professor P. Guillemain.² In Italy, Mr. G. Crugnola had published Papers on reservoir dams, and after the catastrophe at Bouzey Mr. Dumas had collated³ the particulars of a large number of dams of various types of construction. The adoption of a facing in ashlar on the down-stream fall was advocated by Mr. C. Clavenad, it being understood that the bond between it and the body of the dam must be perfect. To counteract the oblique shearing strains he proposed laying the courses (in transverse section) in curves terminating normally to the inclination of the outer face of the wall, thereby counteracting the tendency to sliding. The avoidance of all joints was insisted upon by Mr. Rogeard, making the structure a monolith of cement concrete, similar to that adopted for certain repairing docks, and in enormous masses in the forts of the Meuse. The use of large blocks was preferred by Mr. Hétier. On the interior face, which he would make vertical, he avoided all horizontal courses, and employed random work, the stones being set with their longer dimensions vertical. On the other hand, he recommended on the exterior face the adoption of squared blocks with their beds normal to the face. He also advocated the use of external counterforts, the wall between the counterforts being in the form of a vertical channel. His calculations dealt with the question on the assumption of the mass being an elastic body, in which he

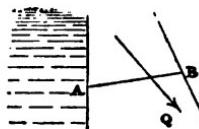
¹ *Annales des Ponts et Chaussées*, vol. xii., 1866, p. 212; vol. ix., 1875, p. 99; vol. xii., 1876, p. 574; vol. xvii., 1879, p. 196; vol. ix., 1885, p. 795; vol. xii., 1886, pp. 248, 550; vol. xiii., 1887, p. 595; vol. vii., 1894, p. 619; vol. x., 1895, p. 77.

² See "Rivières et Canaux," by P. Guillemain, Paris, 1885.

³ *Le Génie Civil*, 1895.

limited the working strains to 9.14 tons per square foot in Mr. Gaudard compression on the exterior face, and to 0.91 ton per square foot in tension on the interior face. In general, masonry was considered incapable of extension, in the application of the law of the trapezium for the resolution of forces on a joint; all joints subject to tension must then infallibly open—a serious matter in the case of a reservoir wall where water percolated, and must exercise dangerous sub-pressure. From this arose the rule that the curves (or resultants) of pressures must be kept within the central third of the whole. Thus Mr. A. Pelletreau (and also Mr. Williot) took as a type a triangular section with the interior face vertical (at least down to the limit of depth = $\frac{\text{resistance}}{\text{specific gravity}}$); this section, with curves of pressure limited to the third of the whole, internally or externally, according as to whether the reservoir was empty or full, was the smallest of the sections without extension. It did not depart much from the section of equal resistance, which was curvilinear. The section, Fig. 2, p. 143, of the Periyar dam, with its irregular profile on the lower face, approached still more nearly to that of equal resistance. Not content with the absence of elongation, under stress, of the masonry of reservoir dams, Professor Maurice Lévy was of opinion that the wall must be made sufficiently thick for maintaining in itself at all points of the interior face a pressure greater than that exerted by the water, so that the tendency was always to expel the latter. In the case of an imaginary joint, A B, Fig. 2, the weight of the superior solid A B C and the hydraulic pressure on A C gave the resultant Q, which in the normal state was balanced by the resultant of the reactions on A B, thanks to the variability of reactions which the deformation developed, according to the measure required to produce equilibrium. But if A B was a fissure into which the water found its way the liquid was not at liberty to graduate its effects, and, in obedience to the law of hydrostatics, it engendered an independent sub-pressure, which could not be balanced by Q. On this liquid lubricating film the mass A B C might slide, or even be lifted and overturned. If, on the other hand, the rotation engendered by the moment of the forces tended to reclose the joint, the reactions of contact between the surfaces of the solids came into play, and restored equilibrium. It might, however, happen that some film of water remained in an open part of the joint, whereby the ordinary law

Fig. 2.



Mr. Gaudard. of the resolution of forces was altered. If the pressure of the water was such as not to follow this law, the joint would close again more or less to compensate for the deficiency by an increase in the reactions of the adjacent solid parts. If, on the other hand, the water exerted a greater pressure, the joint tended to open wider, allowing the advance of the percolating water, augmenting the disruption and danger, the adhesion between the surfaces of the solids diminished, and became more concentrated on the arris B, as the latter tended to become the axis of rotation. But as the conditions of Prof. Lévy were difficult of attainment, in dams of great height, he had suggested another expedient, also proposed by Mr. Le Rond and Mr. E. Coignet. This was to ensure the main core of the dam against contact with high-pressure water by the erection of a guard or masking-wall on the upper side, but connected with and abutting against the main core-wall by cross thrust-walls. On the up-stream face a series of spaces was thus formed, either as vertical wells, or if preferable, as horizontal galleries. The leakage which was unavoidable, through the thin masking-wall, would be carried off by a drain. These defence-walls, or screens, could, according to Mr. Le Rond, be constructed in timber, or according to Mr. Coignet in a series of grooves, or as vertical cylindrical arcs of cement concrete faced with continuous plating. These light arches butting against the ribs of the wall would be at the same temperature as the water, and their elasticity under compressive strain would prevent their cracking.

Much as the law of the trapezium had been contested, nothing seemed to have been found to replace it in current practice. The rule, for instance, might be followed of not resolving the oblique resultant of the forces into a normal force, and into a sliding force, but of taking it entirely as acting normally on the steps of a dentilated section instead of a slope section. This ought to give an excess of security, as resistance to shearing presented by those sides of the steps or dentilations parallel to the lines of force was neglected. The most prominent among the criticisms passed upon the law of the trapezium demanded that it must not be confined to the consideration of horizontal joints but must be applied to the imaginary lines of the joints in diverse directions. It had been shown by Mr. Galliot¹ that the tangential component of oblique pressures, ordinarily neglected, exerted in reality a very prejudicial action. But the theory became so

¹ *Annales des Ponts et Chaussées*, vol. vi., 1893, p. 111.

complex when it was investigated that it seemed improbable that Mr. Gaudard, the simple method of procedure would be abandoned, merely corrected for better or worse by arbitrary or empirical coefficients. It was by employing these approximate methods that engineers had adopted in the calculation of dams pressures varying between 5·5 tons per square foot to 12·8 tons per square foot. At the fifth Congress of Inland Navigation the opinion expressed was that it should be 11 tons per square foot. In the Periyar dam, *Fig. 2*, p. 143, at a depth of 150 feet below the surface of the water, the breadth between a vertical dropped from the interior edge of the crown and the outside face was 120 feet 6 inches, or, say, about 128 feet, including the interior batter. That thickness had been assigned to a depth of about 159 feet by Mr. T. B. Krantz, admitting a pressure of 5·5 tons per square foot; to 138 feet, with a pressure of 5·5 tons per square foot; or to 126 feet, 7 tons per square foot, by Mr. Clavenad; to 130 feet, 7·3 tons to 8·2 tons per square foot, by Mr. Crugnola; to 121 feet, 7·3 tons per square foot, by Mr. Hétier; to 117 feet, 9·14 tons per square foot, by Mr. Guillemain; and to 107 feet, 9·14 tons per square foot, by Mr. Pelletreau. The variations were explainable by certain divergencies in the process of calculation, to the density attributed to the masonry, etc. In the case of the Periyar dam, the working pressure appeared to be about 7·3 tons per square foot. It was to be regretted that the dam was not made curved in plan, as that would (although it was not the case at Furens) have allowed a considerable reduction in its thickness.

A dam might offer resistance in three ways—

(1) As a straight wall resisting by gravity, overturning, and by friction, sliding on the courses. The stability of this system was threatened by the existence of horizontal or sloping fissures, but not by transverse vertical fissures, for every section resisted by itself as the whole.

It was even proposed by Mr. Le Rond to construct such walls divided into segments with an elastic filling in the joints, with a view to the avoidance of the formation of irregular fissures due to contraction in severe winters.

(2) As an elastic plate or slab held fast at a portion of its perimeter, as in the case of a narrow gorge, deep and rocky. These conditions gave rise to mathematical considerations, of which Mr. Souleyre had given an account.¹ The maximum of flexure affected the middle of the free edge, and, notwithstanding the high pressure of the water in the bottom of the ravine, the resist-

¹ *Annales des Ponts et Chaussées*, vol. xviii., 1889, p. 442.

Mr. Gaudard. ance offered would be far from demanding the enormous thicknesses called for to meet the exigencies of the first theory.

(3) Lastly, as the rings of a horizontal arch. If the sides of the valley offered abutments with a solid springing or skewback (as was the case at Periyar), the curved wall, convex on the upstream side, would possess considerable strength. It was by adopting this method that the Bear Valley dam¹ could be reduced to a thickness of 8 feet 6 inches under a head of 43 feet of water. In a curved wall, the transverse joints would be of less importance than in the case of a straight wall, as they tended to close themselves under the pressure of water; and, the horizontal fissures, so dangerous in the case of a straight wall, were of no importance in a curved wall.

But what would happen to a curved dam if it were not firmly grafted into the rock at its ends? It would still offer great advantages. Supposing the dam to be of the same height throughout its length, and not to be fixed at the ends, the horizontal courses, considered as rings of an arch, held together, owing to their mutual fixture, which again rendered dangerous the percolation of water through horizontal fissures. But the weight of the courses, and the locking which resulted, converted the structure practically into a monolith without tendency to dislocation, and would be sufficient to insure against both sliding and overturning. The overturning must be around a rectilineal axis, along the chord of the curve at the foot of the structure; the effect of the curvature was thus to place the greater part of the mass of the wall further from the axis, and to increase the moment of resistance or stability opposed to the pressure of the water.

There seemed scarcely any instances of curved dams falling. That of Puentes was formed of three rectilineal portions; the Bouzey dam was straight, as also was the Habra dam, overturned in 1881, and the Cheurfas and Sig dams destroyed in 1885, whilst the Chéliff dam successfully withstood the trial, thanks to its curvature of 492 feet radius. The Sonzier dam, at Montreux, destroyed in 1888, was a straight wall, this character being adopted as a necessity, owing to its forming one side of a rectangular reservoir. A settlement of the foundation had produced internal cracks, and led to its being overturned. It appeared from the Paper that at one time it had been contemplated to construct the Periyar dam of earthwork. Unquestionably the Author did well not to take that risk. It was true Mr. Decoeur had given it as

¹ Minutes of Proceedings Inst. C.E., vol. ci. p. 857.

his opinion that dams of earth might be rendered more reliable Mr. Gaudard. than those of masonry, which were at the mercy of fissures produced by settlement, effects of varying strain, contractions due to cold, earthquakes, &c. Instead of ramming and puddling the earth with an addition of lime, he obtained as high a degree of stability and greater elasticity by mixing with the earth refuse vegetable fibre, such as leaves, grass, and rushes, ground in a mill similar to that used in preparing the pulp in paper-making. Many of the ancient dams of India owed their high degree of cohesion to the extreme length of time occupied in their construction, such as would now be altogether out of the question. English engineers had been successful in constructing dams of earthwork, subject to as much as 100 feet head. On the other hand, in France, since the example furnished by the disaster at Sheffield in 1864, it had been considered risky to exceed 50 feet, and in place of forming the interior slope with a pitched sloping surface, it had been considered preferable to construct it in a series of inclined steps, forming low vertical faces and benches, which, by confining to certain portions the formation of fissures, should they be formed, in case of settlement, rendered them more easily discerned and repaired.

As regards the means adopted for determining the alignment of the Periyar Tunnel, he recalled the method of procedure of a similar character, but of much greater extent, adopted for fixing the direction of the St. Gothard Tunnel.¹ The Eckhold omnimeter, like the Porro-Moinot-Goulier tacheometer, was an instrument of great value for fixing, by simple sights and corresponding vernier readings, points marked by pegs or signals. In Switzerland, for the detailed topographical surveys for filling in the geodetic figures, great use had been made of the plane-table and stadium, ruled to accord with the Wild method, such as that constructed by Messrs. Kern of Aarau, Switzerland. By their means were transferred directly to the paper, on the ground, with their levels, all the elevated points, and the surveyor, in carrying on his work, was enabled by its aid to execute a faithful and complete representation of the surface in view.

Colonel J. O. Hasted, through whose hands, as Chief Engineer for Irrigation, and Joint Secretary to the Government of Madras, the designs for the works had passed to the Government of India, desired to offer the Author his warmest congratulations on the successful completion of this great undertaking. A name which he thought should not be omitted from mention in connection

¹ M. Pestalozzi, *Die Eisenbahn, 1877.* Digitized by Google

Colonel with the work was that of Captain, now Colonel George Massey Hasted. Payne, who some thirty years ago had been engaged in taking levels for the work, and who was the first, he believed, to recommend a masonry dam. His work was done under considerable difficulties in unexplored jungles, and his reward was jungle fever. He thought the enormous difficulties in carrying out these works would not be appreciated from the modest account given of them in the Paper. All machinery had to be arranged for months, if not years, before it was required, and to be specially designed so that it could be conveyed on country carts over soft roads. If anything broke down, or even an additional pump was needed, it took weeks or months to obtain what was necessary. Skilled labour had to be imported, men taught their work, and ever present among the staff and work-people was the deadly jungle fever, and occasionally cholera. Special reference had been made to the refusal of the Government of India to allow a tunnel in the rock at about river-level for the purpose of passing the discharge of the river during the construction of the dam. Many of the difficulties which were experienced in the construction of the lower part of the dam would no doubt have been prevented by such a tunnel, but by a sanctioning authority the tunnel must be considered a hole near the bottom of the dam, and a possible source of danger which, when such an immense head of water had to be dealt with, was a very serious consideration. By means of self-acting sluice-gates the velocity in the tunnel was to be restricted to 20 feet per second, but there would always be a risk of damage to the self-acting machinery, and if anything went wrong when the dam had been raised to near its full height an almost irresistible force would be let loose at nearly the bottom of the dam. In view of these considerations it was deemed desirable that rather than there should be an opening left at the level proposed, any and every difficulty in construction should be faced. The proposed gates were much the same as those which had been described at the entrance to the large tunnel. The principle was similar to that of the Stoney equilibrium sluice shutters. In the one case the pressure was from outside inwards, and in the other from inside outwards. There was nothing to be said against them. He had always been in favour of the dam being constructed of concrete, and was glad to learn that the great mass of it was of this material. He would like to know whether any leakage had been observed below the dam, and if so, where? It was eminently satisfactory that the dam, while the upper portion of it was still green, had stood an extraordinary flood, an extreme test, without any sign of weakness.

Mr. F. KREUTER, of Munich, had no doubt that, owing to the Mr. Kreuter. considerable resistance to crushing of the material, as stated in the Paper, the structure of the dam was of abundant safety throughout. As to the tunnel, he hoped the fissures met with during its construction, and much more those created by blasting with as high an explosive as gelatine, would not make it necessary to line it with masonry. From the fact that it had not been found necessary to provide means to prevent the escape of water through the natural fissures, these might be concluded to be of slight importance. The numberless imperceptible cracks, however, which were infallibly produced by the use of high explosives, had, at least in Germany, hardly allowed one tunnel to be left rough, as blasted out, even in the toughest and most solid rock. It must be borne in mind, however, that in the Periyar Tunnel the operation of blasting had been performed with great caution.

Colonel PENNYCUICK, in reply to the Correspondence, did not Colonel Pennycuick.

know on what grounds Mr. Fairlie Bruce supposed that "the dam was not connected to the rock either at the base or flanks"; it was carefully let into the rock on both flanks by irregular cuttings in the rock; in the bed of the river the natural face of the rock was so jagged and irregular that little or no artificial cutting was necessary; but throughout the whole area formed by the meeting of the masonry and the rock there was hardly a square yard in which the connection depended upon frictional resistance alone. He thought Mr. Collignon was under a misapprehension as to the reason for making a large portion of the dam of concrete; this was not done for the sake of economy, there being in fact very little difference in the cost of the concrete and rubble, but for the sake of speed; the number of masons available was the principal factor in fixing the proportions of the two materials, and to have constructed the whole dam of rubble would probably have added at least two years to the time occupied in construction. As to any risk from unequal settlement, he could only repeat that he utterly disbelieved in the existence of any such risk; the two materials were practically identical in composition, the proportion of stone not differing by more than 5 per cent. at the utmost, and there was certainly no measurable difference in the rate of settlement. There had been ample opportunities for observing any such difference, if it had occurred, but not the smallest indication of any had been seen. He did not see how masonry could be laid in courses normally to the direction of resultants which varied from day to day with every fluctuation in the level of the water; but apart from this he considered anything in the shape of a "course" to be objection-

Colonel
Pennycuick.

able, and the greatest care had been taken to avoid courses in the masonry actually used. The parallel internal walls noticed by Mr. Gaudard had been put in to divide up the area into sections for convenience of construction. He intentionally refrained from discussing the principles on which the calculation of pressures had been made, as the subject was altogether too complicated and too mathematical to be dealt with in a descriptive Paper. A note on the subject was attached to his original report¹ on the dam written in 1882. It would be seen from what had been said above that he considered courses objectionable and agreed with Mr. Rogeart in considering that the structure should be a monolith, which in point of fact it was, as regards both the rubble and the concrete portions. He was at one time in favour of the use of large blocks, but it was found in practice that the use of any stone larger than could be carried by two men gave more trouble than it was worth, and the smaller the component parts, the more the work approached the monolithic character. The guard wall advocated by Mr. Gaudard and by Messrs. Le Rond and Coignet would no doubt be useful, but he doubted whether its cost might not be more usefully spent on the main wall. With regard to the suggestion that advantage would be gained by a curved plan, he wished to repeat emphatically that he utterly disbelieved in the advantage of this form. In the particular case of the Periyar dam no radius of curvature less than about 2,000 feet could have been used, and if those who imagined that a reduction of pressure for a given thickness, or a reduction of thickness for a given limit of pressure, could be obtained by considering the dam as an arch, would take the trouble, as he had done, to calculate the actual pressures on this theory, they would find that for a given section, with any practicable dimensions, these pressures greatly exceeded those produced in the straight wall. The instance Bear Valley dam was beside the question; there was no analogy between a dam 43 feet high and 450 feet long, and one of four times this height and three times the length, and as a matter of fact the pressure on the masonry of the Bear Valley dam was four or five times that in the Periyar dam, so that the success of the former merely proved that masonry would bear a much greater pressure than it was thought wise to allow in a large work; a point on which he for one had never had any doubt. Of the dams mentioned by Mr. Gaudard, that of Puentes failed from the yielding of the soil on which it was built; that of Bouzey from imperfect design and

¹ Records of the Government of India Public Works Department, No. cert.
Madras, 1886. Appendix I., p. 24.

weak foundation, aided in all probability by the action of frost, Colonel Pennycuick. an action to which the Periyar dam was not exposed, and which in any case was not better resisted by a curved wall than by a straight one. The Habra dam failed from bad workmanship. He was not sufficiently acquainted with the history of the Cheursas, Sig, and Chéliiff dams to be able to say how far the two former would have been safe if curved or the latter have failed if straight, but with regard to the Montreux dam it was clear that the failure resulted from settlement of the foundations, and it was not shown that this would have been avoided by making it curved in plan. The admirable cohesion of the earthwork in Indian dams, noticed by Mr. Gaudard, was not due so much to the time occupied in their construction as to the mode of construction, the earth being deposited in very small quantities and constantly trampled by the feet of the workmen. Modern work was just as good in this respect as ancient; in the case of the Red Hills reservoir, which supplied the city of Madras with water, in which a trench $\frac{1}{2}$ mile long and 50 feet deep was caused by a cyclone in 1884, and which he had restored in the following year, only eight months were occupied from the beginning of the work to the time when the reservoir was again completely filled. In reply to Mr. Kreuter, no difficulty had been experienced nor was any anticipated in consequence of the fissures existing naturally in the rock, or produced by blasting. It must be borne in mind that in the first place the slope of the tunnel was such that the required discharge was produced with little or no head beyond that due to the actual depth of water ($7\frac{1}{2}$ feet), and that any water which did escape through fissures must return to the valley in which the water was to be used; whether it reached the valley by means of the tunnel or through fissures in the bottom or sides of the latter was a matter of indifference.

2 February, 1897.

Mr. JOHN WOLFE BARRY, C.B., F.R.S., President,
in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Members.

ROBERT WEST HOLMES.

ALBERT JAMES HUMBY.

ROBERT BRIDGES MOLESWORTH, M.A.
(*Cantab.*)

JOHN MITCHELL MONCRIEFF.

HOWARD DEVENISH PEARSALL.

PERCY CROSLAND TEMPEST.

BERESFORD GAHAN WALLIS.

And that the following Candidates had been admitted as

Students.

SAMUEL ERNEST ANDREW.
 GIRINDRA CHANDRA BOSE.
 PHILIP REGINALD BOXWELL.
 JAMES HERBERT BROWN.
 THOMAS ANDREW COMMON.
 HOWARD DRU DRURY.
 WILLIAM HENRY ELCE.
 FRANK CORBETT GRIMLEY.
 MAURICE WALTER HENTY.

SYDNEY AINSLIE HOLLIS.
 JAMES PEARSON IRVINE.
 WILLIAM GREGORY KEAY.
 ANDREW HOME MORTON.
 GEORGE NUTTALL SHAWCROSS.
 JOSEPH SHEPHERD.
 ALEXANDER LOGIE DU TOIT, B.A.
 (Cape.)
 REGINALD WELLESLEY WILSON.

The Candidates balloted for and duly elected were : as

Members.

RICHARD BARNESLEY SANDERS, B.E.
 (Royal.)
 JULIUS STANKE.

ABRAHAM McCUSAULD STEWART, B.E.
 (Dubl.)
 TORQUATO XAVIER MONTEIRO TAPAJOS.

ALEXANDER BASIL WILSON.

Associate Members.

RUDOLPH OSWALD AHLERS.
 HARRY PIGOTT ALLISON.
 EDGAR ARTHUR ASHCROFT.
 THOMAS BENNETT.
 THOMAS ROLPH BENNETT, Stud. Inst. C.E.
 PERCY WALTER BERTLIN.
 RUSTAT BLAKE, B.A. (*Cantab.*), Stud. Inst. C.E.
 PERCY MOORE BINGHAM.
 RUDING SPENCE BIRT, Stud. Inst. C.E.
 ROBERT BUCK BROSTER.
 GEORGE JACKSON CHURCHWARD.
 ARTHUR AUSTIN GREAVES DOBSON.
 DOUGLAS DOBSON.
 LOUIS CHARLES JOHN DOXAT, Stud. Inst. C.E.
 FREDERICK HARRY GREENHOUGH, Stud. Inst. C.E.
 HARRY PRESCOT HILL.
 HORACE CHARLES HOLLINGSWORTH.
 RICHARD JOSEPH HOWLEY, Stud. Inst. C.E.

HAROLD SIBSON JACQUES, Stud. Inst. C.E.
 GUY ERNEST LLOYD, Stud. Inst. C.E.
 JOHN TURNBULL MCINTYBE.
 WILLIAM LLEWELYN PHILLIPS.
 GEORGE FRANCIS PITTA, Stud. Inst. C.E.
 JOHN ARCHIBALD POLWHELE, Stud. Inst. C.E.
 GEORGE EDWARD LUTHER POULDEN.
 GILES HENRY POWELL.
 EDWARD HULME RIGBY, B.Sc. (*Victoria*), Stud. Inst. C.E.
 JOHN ROBERTS.
 ROBERT LEWIS SOPER.
 ARTHUR MARINUS ALEXANDER STRUBEN, Stud. Inst. C.E.
 HENRY GOTTRUEX TRENCHARD.
 HAROLD WARREN, Stud. Inst. C.E.
 HENRY BONIFINT GORDON WARREN, Stud. Inst. C.E.
 STEPHEN MAYNARD JENOUR WILLIAMS, Stud. Inst. C.E.
 JOHN EGETON WOOD.

JAMES BROWN WYLLIE.

An Associate.

Vice-Admiral Sir GEORGE STRONG NARES, K.C.B.

The discussion upon the Paper on "The Diversion of the Periyar," by Colonel Pennycuick, occupied the evening.

SECT. II.—OTHER SELECTED PAPERS.

*(Paper No. 2906.)***“ Swing-Bridge at Selby, North-Eastern Railway.”**

By JOHN TRIFFITT, Assoc. M. Inst. C.E.

PREVIOUSLY to the construction of the bridge described in this Paper, the North-Eastern Railway was carried over the River Ouse by a cast-iron double-bascule bridge,¹ built in conjunction with the Hull and Selby Railway, which was opened for traffic in 1840. Its total length was 191 feet 6 inches, and the opening span had two similar leaves, which gave a clear water-way of 45 feet. The leaves were raised or lowered in $1\frac{1}{2}$ minute, by a quadrant and rack worked by hand, two men being in attendance night and day for this purpose and acting as gatemen at the adjoining level crossing. It was a very substantial structure, but the expansion of the iron caused the leaves of the opening span to rise to such an extent that it was necessary to limit the speed of trains passing over them. After the opening of the York and Doncaster branch of the North-Eastern Railway in 1870, the old bridge formed part of the East-Coast main line between London and Scotland; and the traffic over it was further increased by the opening of new branches of railway. In view of the steady growth of railway traffic and the increased weight of the rolling stock, it was decided to divert the railway and to carry it over the river by a new swing-bridge, worked by hydraulic power, on the east side of the old bridge.

The river traffic had priority of the railway traffic over the old bridge, but Parliament consented to the reversal of this order when the construction of the new bridge was sanctioned. In 1887 a census of the railway and river traffic was taken; the former was found to average two hundred and twenty-four trains per day and the latter seventeen vessels per day. The Ouse is tidal at Selby, the difference between high and low water at the bridge being about 7 feet 6 inches, and the width of tideway about

¹ Minutes of Proceedings Inst. C.E., vol. lvii. p. 3.

191 feet. The highest known flood-level at the bridge is about 9 feet 3 inches above high water of ordinary spring tides.

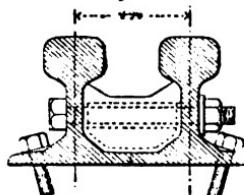
General Description.—The bridge consists of a swing span of 130 feet, with 60 feet of clear waterway, and a fixed span of 110 feet 6 inches, with 54 feet of clear waterway, the headway in each case being 12 feet 9 inches above high water of ordinary spring tides. A general plan of the railway approaches and the river on each side of the bridge is shown in Fig. 1, Plate 4, and a plan and west elevation of the bridge are given in Figs. 2. The swing span is at the north end of the bridge; it turns upon a cast-iron table 31 feet in diameter, bolted to a group of nine cast-iron cylinders, and rests in its normal position upon it, its ends being supported on a masonry pier with piled foundations, on the land side, and on two braced cast-iron cylinders, in the middle of the river. The centre pier is the northern support of the fixed span, the southern support consisting of a masonry pier with piled foundations. The turntable consists of a pivot encircled by two castings, with radial arms and spindles connected respectively with an upper and revolving circular box-girder, and coned rollers which travel between roller-paths bolted to the upper circular box-girder and to a lower one which is bolted to the cylinders. The superstructure and turntable are designed to distribute the loads evenly upon the rollers and pivot. The pumping-engines and accumulators of the hydraulic machinery, by which the bridge is worked, are contained in a building on the north bank of the river. Immediately adjoining the main bridge there are three small bridges, one on the north side, of 10 feet span, over the old towing-path, and two on the south side, of spans of 15 feet 6 inches and 25 feet respectively. Of the latter the first is over a tram-road, and the second is over a subway constructed instead of a public road level-crossing. The hydraulic turning engines are situated and worked in a cabin erected over the railway upon the main girders of the swing span, directly over the pivot. On the north side of the bridge the East-Coast main line and the Hull and Selby line (two double-line railways) converge and then run parallel over the bridge to a junction over the north abutment of the subway. The centre lines of the two systems are $4\frac{3}{4}$ inches apart over the bridge, *Fig. 3*; this arrangement was adopted to bring the junction near to the controlling signal cabin at Selby station. Passenger trains are allowed to travel over the bridge at a maximum speed of 30 miles per hour, but the speed of goods trains is restricted to 20 miles per hour. Between the 1st February, 1891, when the bridge was opened for traffic, and the 25th September, 1894, the

bridge has been turned for river-traffic 3,546 times, or an average of 2·66 times daily.

Superstructure.—The girderwork of the superstructure is throughout of wrought iron, which it was assumed would safely withstand a tensile stress of 5 tons, a compressive stress of 4 tons, and a shearing stress of 5 tons per square inch. There are two main plate-girders in each span, spaced 26 feet from centre to centre, with transverse girders 6 feet 6 inches from centre to centre except near the supports, where the distances vary to suit the special requirements in each case. The main girders are 2 feet and the transverse girders are 1 foot 4 inches wide, with depths varying between 1 foot 4 $\frac{1}{2}$ inches and 1 foot 9 inches. The normal rail-bearers consist of two L-bars, 3 $\frac{1}{2}$ inches by 3 $\frac{1}{2}$ inches by $\frac{1}{8}$ inch, with an intermediate web-plate 9 inches by $\frac{1}{8}$ inch. At each end of the swing span, and where the transverse girders rest upon the turntable, the rail-bearers are of greater depth and stronger construction to firmly brace the transverse girders at those points, whilst the remaining rail-bearers over the turntable consist simply of T-bars. The way-beams are laid between longitudinal L-bars which are riveted to the transverse girders, and support the bridge decking. The latter consists of $\frac{4}{5}$ -inch plates over the roller-path, and where counterpoise is placed; elsewhere it is of $\frac{5}{8}$ -inch buckled strips,

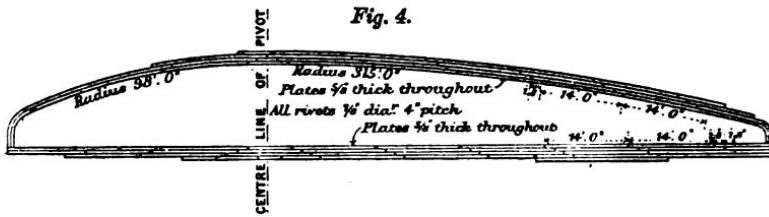
8 inches wide and spaced $\frac{1}{2}$ inch apart. The flange-plates in the main and transverse girders are $\frac{1}{8}$ inch thick, but those in the top flanges of the main girders of the fixed span and in the overhead girders are $\frac{1}{2}$ inch thick. The webs of the main girders of the swing span vary between $\frac{3}{8}$ inch and $\frac{5}{8}$ inch, and those of the fixed span between 1 inch and $\frac{5}{8}$ inch in thickness. The webs of the transverse and overhead girders are $\frac{3}{8}$ inch thick. The gussets of the webs of the main girders are formed either of L-bars and $\frac{1}{2}$ -inch plate, or of T-bars. The longitudinal L-bars in the main girders are 4 inches by 4 inches by $\frac{1}{2}$ inch, all other L-bars in both main and transverse girders being 3 $\frac{1}{2}$ inches by 3 $\frac{1}{2}$ inches by $\frac{1}{2}$ inch, and the T-bars are all 6 inches by 4 inches by $\frac{1}{2}$ inch. The rivets are pitched 4 inches apart, and are $\frac{1}{2}$ inch in diameter in the main girders, and $\frac{3}{8}$ inch in diameter in the transverse and overhead girders. The flange-plate diagrams for the main girders are shown in *Figs. 4 and 5*. The bottom plate of the lower flange in each main girder of the swing span

Fig. 3.

Scale, $\frac{1}{2}$ full size.

is widened to the curve of the supporting cast-iron circular girder, to which it is secured by 1-inch bolts, and the web gussets at those points are consequently splayed out to the greater width of flange. Six of the transverse girders are arranged and connected in pairs by $\frac{1}{4}$ -inch plates to bear upon the turntable over the five innermost cylinders, where they are secured by 1-inch bolts. The swing span has arms of unequal length; on the centre line of the bridge they are 45 feet and 85 feet long respectively, and on the centre lines of the main girders they are 43 feet 1 inch and 84 feet long respectively. The counterpoise on the short arm weighs 92 tons 9 cwt., and consists of cast-iron bars and packings fitted in the end panels of the main girders and between the first three transverse girders; for this purpose these transverse girders have been made specially strong. The transverse girders at each end of the swing span are of trough form, and are designed to receive the hydraulic knuckle-gear which lifts the swing span off the sliding

Fig. 4.



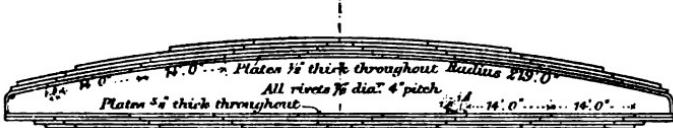
FLANGE-PLATE DIAGRAM FOR SWING SPAN.

blocks previous to turning. The maximum depth of the web is 14 feet 6 inches in the swing-span main girders, and 10 feet in the fixed-span girders. The radii of the upper flanges of the swing-span main girders are 98 feet and 315 feet for the short arm and long arm respectively; in the fixed span the radius is 219 feet, each girder being 110 feet 6 inches long. An allowance of 3 inches has been given for expansion and clearance between the swing and fixed spans.

Turntable and Group of Cylinders.—The turntable rests upon nine cast-iron cylinders sunk to a depth of about 78 feet below rail-level, and founded upon the sandstone rock. The centres of eight of these cylinders are equidistant on the circumference of a circle of 15 feet radius, described from the centre of the ninth cylinder, which is placed under the centre of the turntable. This arrangement places two cylinders under each of the main girders, and the remaining four in the circle are immediately below the two lines of railway. The centre cylinder is 7 feet in outside diameter;

the others are 6 feet in diameter at the base and upwards to a point a little below high-water mark, where they are reduced to 5 feet 4 inches in diameter, and then tapered to a diameter of 4 feet 6 inches at the lower side of the top moulding; this tapered portion with the top and bottom mouldings is 8 feet deep, whilst the other sections of cylinders are each 6 feet deep, without the making-up pieces. The thickness of metal in all the cylinders is $1\frac{1}{2}$ inch, except in the bottom section, which has a thickness of 2 inches immediately above the cutting-edge, Figs. 6, Plate 4. The sections are bolted together by turned bolts of $1\frac{1}{2}$ inch in diameter, Figs. 7, and the planed joints are rammed tight with iron-rust cement. The nine cylinders are firmly connected together by cast-iron bracings, secured by $1\frac{1}{2}$ -inch bolts, and are filled with Portland cement concrete mixed in the ratio of 3 of gravel to 1 of cement. The centre cylinder has an inside cap of granite, but the other cylinders are filled to the top with concrete, having a 2-inch cap in the ratio of 2 to 1. The top section of

Fig. 5.



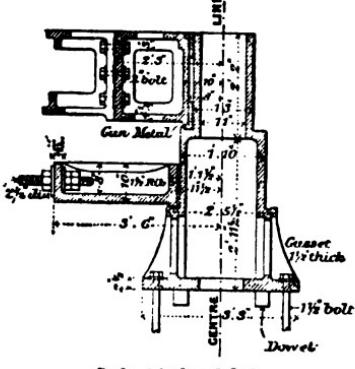
FLANGE-PLATE DIAGRAM FOR FIXED SPAN.

the centre cylinder is octagonal, and 2 feet 9 inches deep; to it are bolted eight cast-iron radial arms, the other ends of which rest upon the outer cylinders, and connect together the eight sections of a lower and fixed circular cast-iron box-girder 1 foot 8 inches deep, the joints being secured by $1\frac{1}{2}$ -inch bolts, Figs. 8 and 9. Each section of the circular box-girder is divided by seven diaphragms $1\frac{1}{2}$ inch thick, those at the ends being planed to form the joints with the radial arms; the webs are $1\frac{1}{2}$ inch thick, and are concentric with the centre line of the roller-path; the flanges are 2 inches thick, the surface of the top one being planed to receive the lower roller-path. Cast-iron deck-plates $\frac{1}{2}$ inch thick rest upon and are bolted to the lower flanges of the circular box-girder and radial arms, which are planed to receive them; the joints are tightly caulked to keep the flood-water from the roller-paths. The pivot of the turntable, Fig. 10, is a strong casting, 2 inches thick throughout, except in the base where it is $2\frac{1}{2}$ inches thick. It rests upon and dowels into a circular granite bedstone

2 feet thick, and is bolted down by four $1\frac{1}{2}$ -inch bolts 5 feet 6 inches long, which pass through the granite and are secured by washers built in the concrete. Its circular base is 3 feet 3 inches in diameter, and its least diameter is 1 foot 3 inches for a depth of 2 feet from the top, where it is increased to 1 foot 10 inches to form a bearing-ledge for a do-decagonal casting, Figs. 8 and 9, Plate 4, and *Fig. 10*, cored and turned to encircle this upper portion of the pivot. The diameter is again increased 1 foot 8 inches lower to 2 feet $5\frac{1}{2}$ inches to form a second bearing-ledge upon which a ring-casting rests. Between the second ledge and the base the pivot is strengthened by gussets $1\frac{1}{2}$ inch thick. To the do-decagonal casting are bolted twelve cast-iron upper radial arms, Figs. 8 and 9, connecting to an upper and revolving circular

cast-iron box-girder, planed on its surface to receive the wrought-iron girder-work, and on its lower face to connect to the upper roller-path. This upper box-girder is 2 feet wide and is made in twelve sections, bolted together with bolts $1\frac{1}{8}$ inch in diameter, both joints and bolts being accurately machined to fit truly. Its flanges are 2 inches, and its webs $1\frac{1}{2}$ inch thick. Each section has diaphragms of $1\frac{1}{2}$ -inch metal spaced about 1 foot 9 inches apart. On two sections a circular socket is cast to receive the bearing of the vertical shafts which transmit the

Fig. 10.



PIVOT OF THE TURNTABLE.

motive power from the overhead-cabin to the rack on the lower roller-path. The upper radial arms are braced together by I castings as shown in Fig. 8. The do-decagonal casting is in one piece carefully machined. The facing-strips in all these castings were designed to be $\frac{1}{4}$ inch thick. The gun-metal bearings round the pivot are $\frac{1}{2}$ inch thick. The roller-paths are of cast steel, each in twelve sections, the surfaces and joints being truly planed, and the latter being made to break with those of the upper and lower circular box-girders. They are secured to the box-girders by bolts $1\frac{1}{8}$ inch diameter, and have a mean diameter of 29 feet.

The circular rack is cast on the outer face of the lower roller-path and was designed to allow the bridge to be turned in either direction; *Fig. 11* shows details of the teeth. The surfaces of the

roller-paths are inclined so that if produced they would be intersected by the axes of the rollers on the centre line of the pivot. There are twenty-four cast-steel rollers, *Figs. 12*, each 2 feet 6 inches in diameter on its centre line, and bevelled to the inclination of the roller-paths. They are 1 foot 1½ inch wide and

Fig. 11.

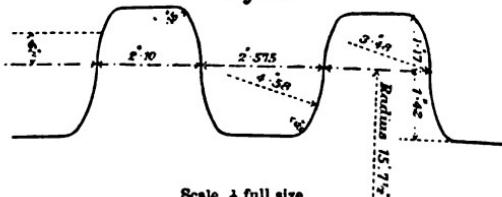
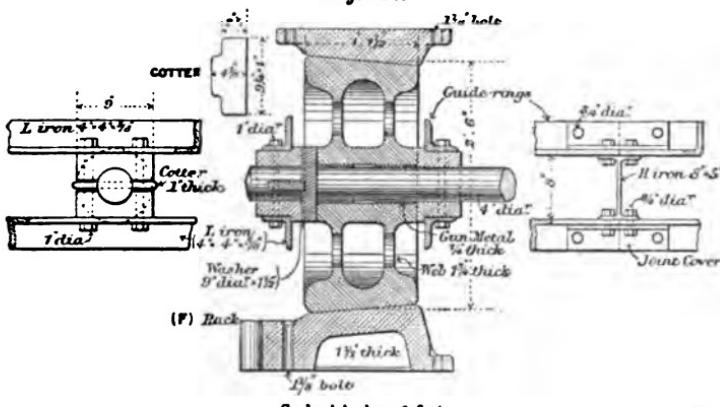
Scale, $\frac{1}{4}$ full size.

DIAGRAM OF TEETH IN CIRCULAR RACK.

double webbed. The rollers and paths are cast in steel, made from a mixture of hematite and Cleveland iron, and annealed. The spindles in the live ring are of wrought iron, 2½ inches in diameter, increased to 4 inches at the axles, the latter having $\frac{1}{2}$ -inch gun-metal bearings. The journals are of cast iron, and are

Fig. 12.

Scale, $\frac{1}{4}$ inch = 1 foot.

CROSS-SECTION OF ROLLER AND ROLLER-PATH.

bolted to L-bar guide-rings 4 inches by 4 inches by $\frac{1}{4}$ inch. The inner rings are in four equal sections, whilst the outer rings are in twenty-four equal sections to allow the removal of any roller. The upper and lower guide-rings are connected and supported at the joints by I-bars 8 inches by 5 inches. The outer face of the roller-boss bears against a wrought-iron washer 9 inches

in diameter and $1\frac{1}{2}$ inch thick. A wrought-iron cotter $9\frac{1}{2}$ inches by $4\frac{1}{8}$ inches by 1 inch, cut away to a width of $2\frac{3}{4}$ inches at each end, locks with the washer and outer-journal bolts, and keeps the roller in its proper position. The spindles have screwed ends and are secured by two adjusting-nuts and a check-nut to a ring casting, 7 feet in diameter, which revolves and rests upon gun-metal bearings interposed between it and the centre portion of the pivot, the support being given by the ledge, previously mentioned. The ring-casting is of trough section, Fig. 9, Plate 4, and of 2-inch metal, with twelve stiffening diaphragms of $1\frac{1}{2}$ -inch metal. Bosses, 6 inches in diameter, are cast and machined for the reception of the spindles. The bridge is turned by the revolution of the vertical shafts, and a bevelled pinion keyed on to each, with teeth fitting into those of the circular rack on the lower roller-path; the pinion is adjustable and may be thrown out of gear. The moving part of the bridge therefore comprises the upper box-girder, roller-path, and radial arms, besides the superstructure, rollers and spindles, but the lower roller-path remains fixed.

Centre Pier.—The centre pier consists of two cast-iron cylinders braced together, Fig. 6, Plate 4, the greatest diameter of each being 8 feet. They rest upon the sandstone rock at a depth of 76 feet below rail-level, and each is filled with Portland cement concrete up to the level of a circular granite bedstone, 2 feet thick. On the swing-span side of each cylinder a strong cast-iron bed-plate is bolted to the granite bedstone to receive the girders in their normal positions; on the other side a cast-iron bearing box is fixed to carry the fixed-span girders.

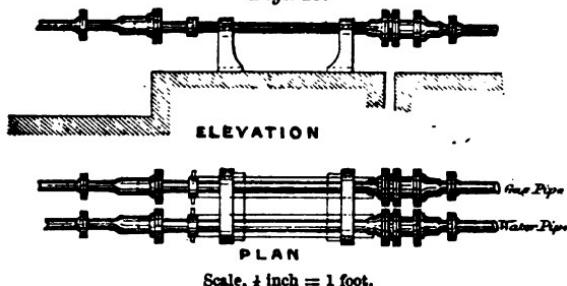
Timber Jetty and Fenders.—The bridge, when open for river traffic, and the turntable, are protected by a substantial timber jetty, Figs. 2, which is also used as a towing-path; whilst the centre pier is protected on the east and west sides by two timber fenders, connected by guiding-bars secured to intermediate piles under the bridge, Figs. 2 and 6. Pitch pine is used throughout, the piles being 13 inches by 13 inches, the bracings 12 inches by 6 inches, and the planking 11 inches by 4 inches, spaced 1 inch apart.

Land Piers.—These are of brickwork masonry and concrete, built upon piles. For both the north and south piers the piles, sills or caps are of pitch pine, 13 inches by 13 inches. In the north pier the sills are bolted between the piles by 1-inch bolts, and in the south pier the caps are morticed on to the piles. Cement concrete in the ratio of 6 to 1 was employed. The south pier was originally designed to consist of two cast-iron cylinders sunk into

the boulder clay, but in carrying out the work the foundation proved to be better than had been anticipated, and a masonry pier was adopted.

Hydraulic Machinery.—The house containing the pumping-engines and accumulators is supplied with water from the main tank of the station-yard, the service-pipes being laid over the bridge, and connected when required at each end of the swing span

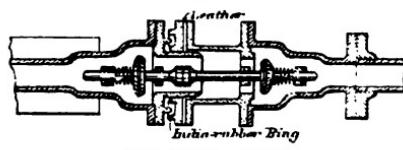
Fig. 13.

Scale, $\frac{1}{4}$ inch = 1 foot.

CONNECTIONS BETWEEN FIXED- AND SWING-SPAN PORTIONS OF SERVICE-PIPS.

as shown in *Figs. 13* and *14*. The house-tank has a capacity of 500 gallons, and is fixed overhead. Two small mild-steel boilers of the locomotive multitubular type, are fed by injectors from the overhead tank, and work at a pressure of 100 lbs. per square inch. These boilers work in weekly turns in conjunction with two steam-pumping-engines, each of which has two cylinders of $5\frac{1}{2}$ inches in diameter, and of 6 inches stroke, and two double-acting force-

Fig. 14.

Scale, $\frac{1}{4}$ inch = 1 foot.

ENLARGED SECTION OF VALVES.

pumps of gun-metal working directly from piston-rods; the cylinders, pumps, and crank-shaft bearings in each case are mounted on a cast-iron tank bed-plate of 100 gallons capacity, containing the water or mixture of water and glycerine which circulates through the hydraulic machinery. When autumn commences the water and glycerine are mixed in the ratio of 1 volume of crude glycerine to 4 of soft water, and in winter the amount of

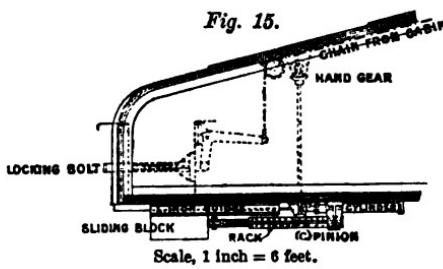
glycerine is increased, the usual ratio then being 1 to 3; but in the severe weather experienced in February, 1895, and in the winter of 1892, the ratio was 1 to $2\frac{1}{2}$, or a density of 20° Twaddell. It has been found that hard water causes the hydraulic valves to groan when under pressure. It is found necessary to replenish the bed-plate tank with $\frac{1}{2}$ gallon to 1 gallon of the mixture per week when in use, and with about 2 gallons of water per week in summer.

The accumulators are in duplicate, as are all the motive and hydraulic appliances. Each accumulator has a plunger 10 inches in diameter and 17 feet stroke, and is weighted with gravel and cast-iron placed within a wrought-iron case moving between vertical guides of wrought-iron and timber, to give a working pressure of 900 lbs. to the square inch. Each accumulator and each engine has a stop-valve to shut off the power from the main

and accumulator respectively, and an automatic steam regulator connects each engine to both accumulators, momentum or safety-valves being also provided. The bridge is turned by working one steam-engine and one accumulator together. The pressure- and return-

pipes are carried underground and in boxing from the accumulator-house to the bridge-pivot, where the pressure-pipe enters the return water-pipe, emerging above the turntable. The two sets of turning engines and gear are independent of each other and are placed diagonally in the overhead cabin. Each turning engine has three oscillating cylinders with plungers 3 inches in diameter and 12 inches stroke and gun-metal working and reversing valves.

The apparatus for raising and blocking each end of the swing span when across the river, Figs. 7 and 9, Plate 4, and *Fig. 15*, consists of a hydraulic lifting-cylinder with double rams, $7\frac{1}{2}$ inches in diameter with a stroke of $8\frac{3}{4}$ inches, connected by struttied bars to toggle and knuckle joints; a pair of returning cylinders, 3 inches in diameter, with a stroke of $8\frac{3}{4}$ inches, acting under constant hydraulic pressure to raise the knuckle joints after the bridge has been blocked; two sliding blocks, one under each girder, and each worked by a double-acting hydraulic cylinder;



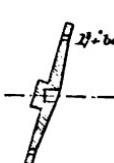
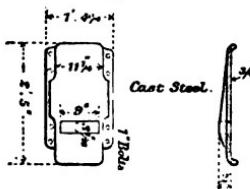
LOCKING-BOLT AND SLIDING BLOCK.

and cast-steel bed-plates upon which the sliding blocks and swing span rest when in their normal positions, and upon which the knuckle-joints descend and by their pressure slightly raise the bridge. In addition to the hydraulic apparatus, hand-lifting gear has been provided, Figs. 16 and 18, consisting of two capstans placed on the centre line of the bridge, and connected by shaftings and spur and bevel wheels to four gun-metal screws fixed in the bed-plates, one under each corner of the swing span; each screw is $6\frac{1}{2}$ inches in diameter and has a pitch of 1 inch. The sliding blocks may be worked by a hand-lever connected to shafting, bevel wheels and a rack, Fig. 17 and *Fig. 15*. Four men are required to open the bridge by hand-power. The bridge can be opened and closed by hydraulic power in five minutes, but the average time is seven minutes.

Locking-Bolts.—The swing span is locked in its normal position by two spring bolts each 4 inches by 3 inches, one of which locks into a cast-steel plate fixed on the north abutment, Figs. 18 and *Fig. 19*, and the other locks into a similar plate fixed on one of the main girders of the fixed span, Figs. 17 and *Figs. 20*. These locks are placed diagonally on the bridge, but on the Figs. they are shown on one girder. The bolts are worked from the overhead cabin to which they are connected by a treadle and chains.

Erection.—The contract for the new bridge and railway diversion was let on the 13th October, 1888, to Messrs. Nelson and Company of York. Mr. John Nelson personally conducted the work for his firm, and Mr. A. Hurst was Mr. Copperthwaite's representative on the ground. The Cleveland Bridge and Engineering Company, of Darlington, were the sub-contractors for the construction and erection of the ironwork, including the sinking of the cylinders, and made the first delivery of cast-iron cylinders on the 26th February, 1889.

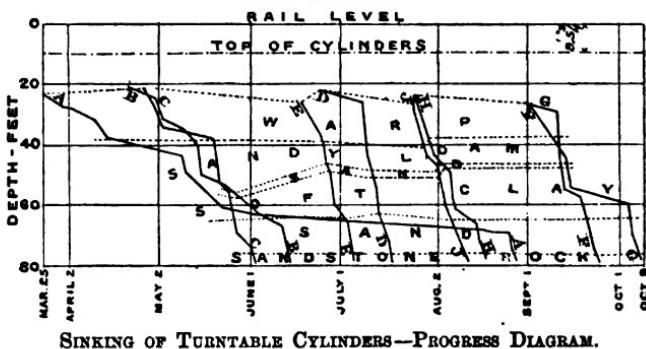
Diagrams showing alphabetically the order in which the cylinders were pitched and the rate of progress in sinking them are shown in *Figs. 21* and *22*. The centre cylinder, A, Figs. 2, Plate 4, 7 feet in diameter, was the first pitched, but the sinking of it was very slow; the delay was owing to some of the sections of cylinders

Fig. 19.*Figs. 20.*Scale, $\frac{1}{4}$ inch = 1 foot.

LOCKING-PLATES.

proving slightly defective and new sections being cast to replace them. It was decided to sink each cylinder as far as possible between guide piles, by excavating below its cutting-edge, and afterwards to weight it with the counterpoise of the bridge. The cylinders were sunk 10 feet to 12 feet before any weight was added and then it was gradually increased, in some cases to 80 tons. The material was excavated by hand-labour. Two air-locks were used, so that two cylinders could be sunk together; the working pressure did not exceed 28 lbs. per square inch. The average daily rate of progress for each of the turntable cylinders was 1·28 foot, and excepting the centre cylinder A, the average daily rate was 1·92 foot. All the cylinders were let about 18 inches into and founded upon the sandstone rock at a depth of about 78 feet below rail-level. In sinking the turntable cylinders

Fig. 21.



SINKING OF TURNTABLE CYLINDERS—PROGRESS DIAGRAM.

a difficulty was encountered owing to the unstable condition of the river-bank, which slipped towards the river and carried the cylinders with it; in consequence, all these cylinders were unavoidably founded slightly southwards and westwards of their true positions, the centre cylinder being most troublesome in this respect, it being 11 inches southwards and $5\frac{1}{2}$ inches westwards of its correct position, none of the other cylinders being more than 3 inches out. To meet this difficulty, the making-up piece for cylinder, A, was cast in a swan-neck form which brought its upper end into the true position, and the bracings between all the cylinders were cast to the altered dimensions. The making-up pieces for the other cylinders were of an ordinary character with the exception of that for cylinder, F, which tapered between $1\frac{9}{16}$ inch and $\frac{5}{8}$ inch in depth and was made of wrought iron. Each 6-foot cylinder was tested with a weight of 200 tons, the

7-foot cylinder with a weight of 250 tons, and each 8-foot cylinder with a weight of 300 tons, during a month's period in each case; old rails and the cast-iron counterpoise were used for this purpose. In no case did the test-weight produce a further settlement. The bolt-holes of each section were drilled to template, and the sections were therefore inter-changeable. The three lowest sections of the cylinders were filled with concrete under air-pressure, and great care was taken to make the concrete solid by grouting it at the junctions of the sections.

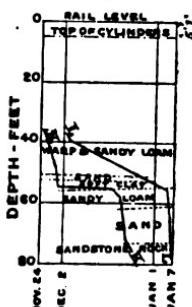
No serious difficulties were met in the construction of the masonry piers. The piles were driven until the set was not more than $\frac{1}{8}$ inch from a 22-cwt. ram falling 5 feet. The Portland cement concrete is in the ratio of 6 to 1, and second-hand rails were embedded in it longitudinally to give additional strength.

A separate contract for the hydraulic appliances was let to Sir William Armstrong, Mitchell and Company of Elswick, and the signal work in the same way was let to Messrs. McKenzie and Holland of Worcester.

The old bridge, shortly after the new bridge was brought into use, was taken down by Messrs. Nelson and Company.

Signals.—There are three block cabins directly controlling the traffic over the bridge, namely, Barby Cabin, Station Cabin and West Junction Cabin, Fig. 1, Plate 4; but the bridge is locked directly from the Station Cabin only. The Bridge Cabin has no instrument to indicate the approach of a train, and no signalling of trains is done from it, but it contains the engines for turning and securing the bridge, Figs. 2 and 9, and a key or releasing lever, Fig. 24, controlling these operations, which is locked mechanically and electrically from Station Cabin. For the electric lock Sykes instruments are used. Barby Cabin is fitted with Sykes lock and block instruments, to which needle-dials have been added for working the up-line traffic. Its up home signals are further controlled by the ordinary slot arrangement worked from Station Cabin, the latter cabin having no up distant signals. The up stop signals of the Station Cabin are locked at danger by the withdrawal of the sliding blocks of the bridge, and they cannot be lowered if the blocks are not in their proper positions. The following are the operations in opening the bridge for river

Fig. 22.

SINKING OF CENTRE-PIER CYLINDERS—
PROGRESS DIAGRAM.

traffic:—The steersman in the Bridge Cabin intimates to the Station Cabin by bell-signal that the bridge is to be turned. The Station Cabin signalman, having the up-line signals of Barlby Cabin normally locked at danger, by special code signals asks for "release" from West Junction Cabin. When this has been given he fixes the dial-needles of the block instruments for the down lines at "train on line," and locks them, and also backlocks all the down-line signals of West Junction at the "danger" position, by pulling over his No. 14 lever. He then pulls over No. 13 lever to release the mechanical lock in Bridge Cabin, and proceeds to electrically release Bridge Cabin and backlock his own No. 13 lever. The steersman in the Bridge Cabin, by pulling over his releasing lever, backlocks the corresponding lever in the Station Cabin, disengages the whole of the bar and signal rodding, Figs. 23 and 24, at both ends of the swing span, disconnects the electric wires at the south end of the swing span, Figs. 24, releases the clutches whereby the turning engines are brought into gear, and releases the levers of the hydraulic lifting cylinders and sliding blocks, and the treadle which actuates the lock bolts. The steersman first admits hydraulic pressure to the lifting cylinders to raise each end of the bridge about $\frac{1}{2}$ inch, and then to the front of the four sliding blocks and withdraws them. An indicator for each block denotes in the cabin if it has been fully withdrawn. He then lowers the bridge ends, and by the treadle withdraws the two lock-bolts, inserts the clutch of one turning engine, admits hydraulic pressure into the turning engine, and, governing the hydraulic pressure by the hand-wheel, turns the bridge; a dial under the wheel indicates how far the pressure-valves are open. The river traffic is controlled by a double-armed semaphore secured to the fixed span of the bridge and worked by a plunger bearing against one of the sliding blocks of the swing span, or by a lever in Station Cabin. The mode of disengaging the rodding and electric wires is shown in Figs. 23 and 24.

Weights and Costs.—The most important of these are given in the Appendix. The total cost of the river bridge, including the hydraulic and signalling appliances, was £22,342 18s. 10d. The total cost of the bridges and railway diversion was £30,948 13s.

The plans of the new bridge were prepared by Mr. H. Copperthwaite, M. Inst. C.E., and were approved by Parliament, by the Trustees of the River Ouse Navigation and by the Board of Trade.

The Paper is accompanied by seven tracings, from which Plate 4 and the *Figs.* in the text have been prepared.

APPENDIX.—WEIGHTS AND COSTS.

	Weight.	Cost.	Per Lineal Foot.	Per Square Foot.	Per Ton.
	T. C. Q. Lbs.	z. s. d.	z.	z.	z.
		<i>Superstructure.</i>			
Fixed span; wrought iron in main girders, transverse girders, bracings, rail-bearers and decking .	130 0 0 0	1,527 10 0	18·76	..	11·75
Swing span; wrought iron in main girders, transverse girders, bracings, rail-bearers, decking and overhead girders	193 2 0 14	2,268 19 11	17·87	..	11·75
Cast iron in counterpoise	92 9 0 0	516 9 4	..	..	5·58
Cast steel in locking-plates	0 5 2 23	17 2 4	..	..	60·00
Way-beams and bolts for same . . . .	.. ..	109 2 4			
Bridge cabin . . . . .	.. ..	167 2 6			
		<u>4,606 6 5</u>			
		<i>Turntable.</i>			
Cast iron in circular-box girders and their radial arms, centres and bracings	79 2 3 0	781 2 2	..	..	9·87
Cast iron in pivot, live ring, screen and floor-plates	23 19 0 0	285 19 10	..	..	11·94
Cast steel in rollers, roller-paths and rack	45 15 0 0	1,601 5 0	..	..	85·00
Wrought iron in live ring (exclusive of bolts)	8 13 0 0	171 18 4	..	..	19·87
Wrought iron in bolts	1 11 2 4	36 15 10	..	..	23·33
		<u>2,877 1 2</u>		3·81	
		<i>Substructures.</i>			
Cast iron in cylinders	462 0 0 0	4,851 0 0	6·49	..	10·50
Excavation in sinking cylinders . . . .	.. ..	96 9 0			
Cast iron in bracings of cylinders	21 14 0 0	200 14 6	..	..	9·25
Wrought iron in bolts	5 2 0 5	118 0 2	..	..	23·33
Cement concrete in cylinders . . . .	.. ..	606 0 0			
Granite in cylinders . . . . .	.. ..	74 5 0			
		<u>5,916 8 8</u>	7·80		
North pier (complete) . . . . .	.. ..	628 16 0	..	1·23	
South pier . . . . .	.. ..	440 17 4	..	1·21	
Timber jetty . . . . .	.. ..	1,552 9 9	..	0·27	
Timber fenders (complete) . . . . .	.. ..	119 12 0			
Cast iron in bed-plates and boxes . . . . .	.. ..	104 8 2	..	..	9·25
Miscellaneous . . . . .	.. ..	40 6 2			
House for pumping-engines and accumulators . . . . .	.. ..	652 6 3			
Hydraulic engines, accumulators and appliances . . . . .	.. ..	3,932 5 0			
Signals, signal cabins and interlocking, including electric appliances . . . . .	.. ..	1,442 1 11			
Total cost (exclusive of steam boilers and permanent way) . . . . .	.. ..	22,342 18 10			

(Paper No. 2994.)

“The Wagga Wagga Timber Bridge, N.S.W.”

By PERCY ALLAN, Assoc. M. Inst. C.E.

To replace the timber bridge over the Murrumbidgee River at Wagga Wagga, Fig. 1, Plate 5, which, after a life of thirty-three years, was found to be beyond repair, it was decided in 1892 to erect a new bridge, with larger river spans, to avoid the rafting of timber which occurred in time of flood with the small 70-foot spans in the old structure. Tenders were invited for an iron bridge, but, the cost proving excessive, the Engineer-in-Chief for Public Works, Mr. Hickson, M. Inst. C.E., determined to erect a timber structure, and approved the Author's design for a truss bridge, with a larger floor space per span, 3,165 square feet, than any other timber structure erected in the Australian Colonies. In this bridge full advantage has been taken of the abundant supply of good hardwood which the colony possesses. The flooring is of tallowwood, an even-grained timber, free from gum veins, and the best colonial hardwood for the purpose, having a life, under similar conditions to those at Wagga Wagga, of about thirteen years. The floor beams, stringers and truss-work are of ironbark, the truss members being sawn free from heart and sapwood, to ensure mature and sound timber. The average of a number of tests shows this most favoured of Australian hardwoods (for structures exposed to the weather) to have a tensile strength of 8 tons per square inch, a crushing strength of $4\frac{3}{4}$ tons per square inch, and a shearing strength along the grain of 1 ton per square inch; whilst its durability may be inferred from the fact that some roughly constructed bridges have in some cases attained a life of over fifty years, many over thirty-five years, and but few less than twenty-five years. A prolonged life may, therefore, be anticipated for bridges of more mature design, in which greater attention is paid to the inspection of timber, and more care taken in construction.

The truss spans are designed to carry a distributed live load of 1·2 ton per lineal foot, or a concentrated load of 16 tons, with

9½ tons on a pair of wheels. The wind-pressure allowed for is 56 lbs. per square foot on the exposed surfaces of curbs, stringers, and ends of planking, and on twice the area of the handrails, ends of transverse girders, top and bottom chords, braces and verticals, the whole being regarded as a uniform moving live load. The colony is subject to violent gales, a remarkable one being the Dandenong gale in September, 1876, during which a velocity of 153 miles per hour, equal to a pressure of 117 lbs. per square foot, was recorded at the Sydney Government Observatory; but such phenomenal pressures extend only over small areas. Many of the existing structures throughout the colony would not now be standing had they ever been subjected to pressures approaching that allowed for in the Wagga Wagga bridge, which may be regarded as somewhat in excess of actual requirements.

The bridge was opened for traffic on the 11th November, 1895, and consists, Figs. 2, of six timber trusses resting on cylindrical iron piers and a concrete abutment, forming three spans, each 110 feet 3 inches long, and nine approach spans each 35 feet long. The carriageway is 24 feet 4 inches wide, whilst one 4-foot 6-inch footway is arranged for on the up-stream side of the bridge. The comparatively large carriageway is necessitated by the requirements of the wool traffic which crosses the structure, a loaded wool-wagon measuring 11 feet 6 inches over all. The trusses, Figs. 3, stand 27 feet 1 inch apart from centre to centre, and are connected at the top and bottom by a system of lateral bracing, consisting of timber transverse struts and wrought-iron diagonal tie-rods; angle- and portal-brackets being provided in the top lateral system. Each truss is formed of wrought-iron vertical suspension rods, diagonal timber struts and timber top and bottom chords, arranged in seven panels. The trusses are 21 feet deep between the centres of triangulations, fully providing for a loaded wool-wagon, which requires 17 feet 6 inches head room.

To prevent the lodgment of water, open top and bottom chords, consisting each of two timbers cut free from heart, and spaced 6 inches apart, were adopted, thus permitting of the easy renewal of these important members, which are also always accessible to the brush. The joint in each flitch in the bottom chord is effected by means of two 14-inch by $\frac{1}{2}$ -inch wrought-iron plates placed on each side of the flitch stick. On each of these plates, four wrought-iron strips, 14 inches deep by 3 inches wide and $1\frac{1}{2}$ inch deep, are riveted and are let tightly into the timber, being designed to take the whole of the stress. The stress in each flitch is

50 tons, and as the four strips have a total bearing area of 84 square inches, a factor of 8 is provided against crushing; whilst for shearing along the grain a minimum factor of 13 is provided, irrespective of any assistance obtained from the bolts passing through the plates and fitch. The diagonal braces are formed each of two sawn timbers free of heart, bowed to prevent warping and twisting, and connected together by bolts and hardwood distance-pieces. The horizontal thrust from the braces is taken by castings, having lugs $1\frac{1}{2}$ inch deep let into the chords.

In most of the American Howe trusses, counterbraces are introduced, to give lateral stiffness to the main braces. The great strength of ironbark, however, rendered this unnecessary in the Wagga Wagga bridge, and counters have been provided only in the centre bay, where the analysis showed them to be required. The deck consists of sawn transverse planking spiked to longitudinal stringers, seated on the lower lateral wind-struts. The lower lateral struts are adzed down on their upper surfaces to give a 2-inch camber in cross-section of the deck, whilst the centre line of the strut is placed in the same plane as the centre line of the bottom chord. The ends of the lateral strut are secured to the bottom chords by wrought-iron brackets; to these are attached the lower lateral diagonal tie-rods, the centre-lines of which—if produced—would intersect at the centre of bottom chord. The triangulation lines of the wind-bracing and truss-members thus intersect at a common point, avoiding all bending stress in the bottom chord. The lateral struts are tightly dapped 1 inch over nine sawn packing-blocks resting on the floor beams; these blocks not only raise the lateral struts to the same plane as the centre line of the chord, but also equally distribute the whole load over the pair of floor beams at each apex. As the width of the two floor beams at each apex is 2 feet 5 inches, it was impracticable, without fouling the braces and suspension-rods, to support them on the upper edge of the bottom chord; they are therefore suspended from the chords, each pair by sixteen beam-hangers, $1\frac{3}{8}$ inch in diameter, passing on each side of flitches of the bottom chords.

By the adoption of this floor system, the shock from passing loads was reduced by the lateral strut and distributing-blocks acting as a cushion; whilst the shortness of the beam-hangers permitted of a large allowance being economically made for dynamic action. Again, as only direct stresses had to be provided for, an appreciable saving in material was effected.

Any member of the bridge can be renewed separately. The top and bottom chords, consisting of two pieces, the suspension-rods and beam-hangers can be removed and re-arranged to throw the whole weight on one flitch, there being no stress on the remaining flitch; any member of the top and bottom chords can be replaced with sound timber. By loosening the suspension-rods and inserting temporary struts, the braces can be renewed; whilst the removal of the floor beams, stringers and decking is obviously a simple matter. The minimum factor adopted in the trusses is 7 for the stresses due to combined dead and live loads. This may appear somewhat liberal, but the ultimate strength of ironbark having been taken from tests of small specimens of picked timber, less relative strength is to be anticipated in large scantlings. Again, as the flitches were sawn, the grain will run more or less across the line of the stick; and, as defects in timber are liable to escape even the closest inspection, it is necessary to make a wide allowance to cover such contingencies.

The cylinders, Figs. 4 and 5, were sunk under air-pressure to a gravel foundation, and, after the material within them was excavated, were filled with cement concrete. The maximum pressure on the foundation when the bridge is fully loaded is $5\frac{1}{2}$ tons per square foot, neglecting any supporting-power derived from buoyancy or skin-friction. The piles in the platform forming the foundation for the concrete abutment were "blunt pointed" and driven without shoes to a depth of 20 feet; the set, for the last three blows of a 20-cwt. ram falling 10 feet, being 1 inch. The maximum load carried on a pile-head is 25 tons when the bridge is fully loaded. With the exception of the cylinder plates and a few sections of L-bar, all the wrought-iron bars were rolled from scrap at the Lithgow Ironworks, 97 miles distant by rail from the Atlas Company's works in Sydney, where all the ironwork was manufactured, being then forwarded by rail to Wagga Wagga, a distance of 310 miles. The whole of the timber was brought from the northern rivers of the Colony to Sydney, 150 miles by sea, and thence by rail, 310 miles, to Wagga Wagga.

The cost of the superstructure of one 110-foot truss span, erected complete in position, was £1,300, whilst the total cost of the bridge and earthwork approaches was £14,200.

The Paper is accompanied by six drawings from which Plate 5 has been prepared.

(*Paper No. 2987.*)

"Railway Steam-Ferries in Denmark."

By JOHANNES ANDREAS PRIOR.

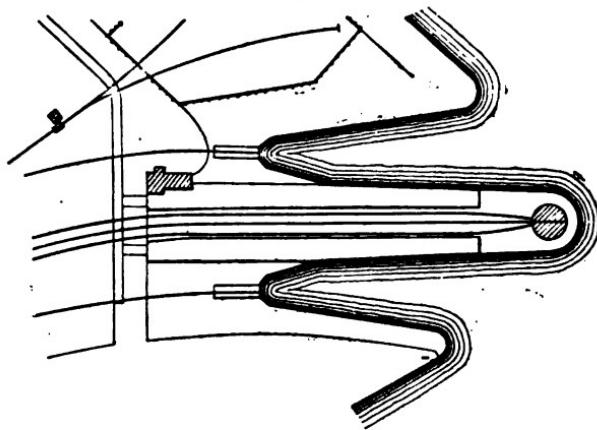
THE kingdom of Denmark comprises a large number of islands scattered between the Jutland Peninsula and Germany on the west, and the Scandinavian Peninsula on the east. The Sound lies between the largest of the islands, Zealand, and the Swedish province Skåne. Between Zealand and Jutland is situated the next largest island, Fünen, which is separated from the former by the Great Belt, and from the latter by the Little Belt. Connection of the railways in Denmark has accordingly necessitated crossings of these waterways, which, on account of their international character and other difficulties, allowed only partial use of bridges, whilst submarine tunnels had to be abandoned as too expensive. Steam-ferries, capable of carrying railway wagons, had therefore to be resorted to. The first was constructed in 1872 to connect Jutland with Fünen over the Little Belt. The connection over the Great Belt, between Fünen and Zealand, was established in 1883, and over the north part of the Sound, between Elsinore on the Danish side and Helsingborg in Sweden, in 1891. In 1895, communication was also established between Copenhagen and Malmö, thus allowing railway wagons of the normal gauge, 4 feet 8½ inches, to pass, without unloading, from the remotest stations in Norway and Sweden to the continent of Europe.

The distance across the Little Belt is only about 1½ nautical mile, and here, as well as across the north part of the Sound, where the distance is about 2½ nautical miles, ferry-steamers of a small type, Figs. 1, Plate 6, could be employed. These vessels, crossing in about 12 minutes or 20 minutes, can deal with a large traffic by continuous day and night service. The distance across the Great Belt is about 14 nautical miles, and across the south part of the Sound about 16 nautical miles; on account of the longer time required in crossing, and the more exposed nature of the sea, ferry-steamers of a larger type, Figs. 2 and 3, had to be used.

Beside the railway connections on the international routes referred to, other railways of the country are similarly connected by steam-ferrries. The Danish State Railways have now seven connections of this kind, beside one by ordinary mail steamers from Korsör in Zealand to Kiel; and a fleet of twelve paddle-wheel and three screw ferry-steamers, and four paddle-wheel and seven screw steamships, aggregating a total registered tonnage of 12,932 tons, and 20,650 I.H.P. Several of the vessels are specially built for the winter traffic to encounter difficulties from ice.

Transhipment of railway wagons can only be effected when suitable means of connecting the lines of rails on shore with those on board the vessels are provided. In this respect Denmark

Fig. 5.



PLAN OF DOCKS FOR TRANSHIPMENT.

possesses the advantage that, in its position at the mouth of the Baltic, the tidal rise and fall of the North Sea is little felt. The difference of levels is for the most part dependent on the prevailing winds; those from the north-west cause a rise, whereas winds from south to east cause a fall, giving a range of levels seldom more than 2 feet above or below the normal. The docks, where the transhipment is effected, are shown in Figs. 4, Plate 6, and *Fig. 5*. Wooden piles are driven into the ground in lines corresponding to the outer shape of the ferry-steamers, which, when lying in the dock, can thus be kept in an exact line with the rails on shore. Elasticity is given to these piles, to meet the shock of the ferry-steamers when entering the dock, by inserting buffer-springs

between the upper ends of the piles and the quay-walls. At the inner end of the docks two groups of piles are fixed to take the thrust endways, and prevent the ferry-steamer approaching too near a strong iron girder-bridge, Figs. 6, 7, and 8, Plate 6, 59 feet 10 inches in length, hinged at the shore end, Figs. 7. Upon the end of the vessel is fixed a suitable bracket to take the movable end of the bridge when lowered. Upon this bridge rails are laid, corresponding with those on shore and on board the vessels. To ensure an exact position of the bridge relatively to the ferry, a pin, Figs. 8, is fixed upon its end, in a vertical position, to drop into a hole in the bracket on the ferry-steamer, thus keeping both together, but at the same time allowing them to accommodate themselves to each other according to the angle of inclination of the bridge or the heel of the vessel. This is effected by suspending the pin from hinges on the head of the bridge, which is again hinged to the girders, the cross connections of which are also hinged. When the bridge is lowered upon the brackets, the lines of rails on board and ashore are continuous and the transhipment of wagons can take place. When the weight is thus transferred to the ferry-steamer its end next the land will be pressed down and its other end lifted until all the wagons are on board. To accommodate this movement, the movable end of the bridge end is suspended by chains connected to counterweights, which leave the bridge so much heavier that it always follows the movement of the ferry-steamer, whereas the winch gear, which is applied for lifting the bridge out of connection, is left free to revolve until the wagons are transhipped, when the bridge is lifted to its highest position free of the ferry-steamer, and the winch gear is locked by pawls. The winch is driven by electricity at both the Danish sides of the Sound; elsewhere the movement is effected by hand, as shown in Figs. 9 and 10.

Two methods of suspending and lifting the bridge are used. At the Danish side of the Sound, two separate winches, Figs. 9, are applied, one at each side of the bridge, with the counterweights working in wells below the surface; the other, Figs. 10, allows the counterweights to work above the surface, and they are therefore placed inside tower-like erections, connected at the top, and forming a kind of portal. This arrangement allows only one winch to be used, and has the further advantage that the counterweights check each other. The features of the arrangements are otherwise identical at all the docks, which only vary according to the size of ferry-steamer.

The ferry-steamers are constructed symmetrically at both ends,

and are supplied with rudders forward and aft, so that the transhipment is independent of the direction in which the ferry has entered the dock. This is of importance at the short crossings, where a turning at each passage would detain the ferry too long. To effect a quick and ready handling of the ferries steam steering-gear is used. Upon the decks are placed steam-winches for ordinary hauling, and for moving the wagons in case the locomotives cannot do so; otherwise the movements of the wagons are effected by the locomotive, the bridges and ferry-steamers being constructed strong enough to carry these heavy loads.

On the Little Belt and over the north part of the Sound, ferry-steamers of a small type, Figs. 1, having only a single line of rails, on which six ordinary goods wagons can be taken at a time, each loaded with 10 tons, are employed. The vessel taken as an example is the "Thyra," built in 1893, by Messrs. Burmeister and Wain of Copenhagen, for service on the Elsinore-Helsingborg route.

On the Great Belt and on the Copenhagen-Malmö route larger ferry-steamers, having double lines of rails, are used. The most recent vessel, the "Kjöbenhavn," Figs. 2, built in 1895 by the same firm, can take eighteen goods wagons, loaded with 10 tons each. As the double line of rails are laid out with curves to meet each other at the ends, very long wagons can only be embarked when fitted with bogie frames. The continental saloon carriage belonging to H.R.H. Prince of Wales, has often been thus brought across the Great Belt upon the older double-line ferries; and the largest saloon carriage of this kind which has been taken across, had a length of 60 feet and a breadth of 9 feet 7 inches, with a wheel-base of 52 feet 10 inches. The reason for laying out the rails with curves, was to avoid broad square-shaped ends to the vessels, which would be objectionable in a heavy sea, and to retain as far as possible the shape of a ship. The ferry-steamers behave exceedingly well in rough weather, and easily carry heavy deck loads; they keep time and are easily handled, regardless of the weather. Large bilge-keels contribute to the steadiness of the vessels, which are propelled by feathering paddle-wheels, which also add to the steadiness, but are not suitable for working in heavy ice. The limited depth of water, however, in the harbours, necessitated the use of paddle-wheels, and to meet the occasional occurrence of heavy ice several spare steamers are required, specially constructed as ice-breakers, but necessitating unloading of the wagons.¹ These spare vessels also include two single-

¹ Minutes of Proceedings Inst. C.E., vol. xcvi. p. 300.

lined twin-screw ferry-steamers for transhipment of wagons over the Little Belt, when the ice is too strong, and also one double-lined single-screw ferry-steamer for the Great Belt; these screw boats have done very good service. The vessels are not used for through passenger-train service, as passengers in general prefer to leave the carriages while crossing, but mail- and luggage-vans are always taken across, as are also single through passenger carriages on the short crossings. The decks are built flush, with as few encumbrances as possible; and funnels, companions and skylights are arranged according to the position of the rails. At both ends of the deck are placed booms, corresponding in height with the buffers on the wagons, and easily lifted when necessary for taking wagons off or on. They serve to check the movement of the wagons, which, however, must be tied longitudinally during the passage by chains fixed to eye-bolts in the deck, and by booms across the rails and under the wheels. The wagons are besides tied transversely by screw tighteners applied to the tops of the rails. A bridge is erected amidships, high enough to allow the largest wagons to pass below, and on it is placed the steering-house, with a separate connection so that each rudder can be worked independently. To support the rails and the considerable weight that may traverse or rest upon them, the deck beams, upon which they are fixed, are supported by longitudinal girders resting upon pillars from the floor. The flat-bottomed rails are firmly riveted in troughs of iron, which are partly filled with cement. The deck is of wood adjoining this trough, and the rails project about $1\frac{1}{2}$ inch above it. In all the ferry-steamers are arranged large and airy saloons for first- and second-class passengers at one end below deck, and at the other end similar saloons for third-class passengers. The vessels are lighted throughout by electricity, and are heated by steam. Ventilation is effected from the funnels, which are double, the space between the inner and outer portions being in connection with the rooms, and exhausting the foul air. Several Boyle exhaust and down-cast ventilators are also installed. On the decks are placed four pillars, from which are suspended arc-lamps for lighting the deck while embarking passengers or wagons. The vessels are built of steel to the highest class in the "Bureau Veritas," and the engines are compound, working diagonally, with surface condensation. A special centrifugal pump, with its own steam-engine, supplies the cooling water. The starting and reversing is simply and quickly effected by steam-power.

The dimensions of the two types of ferry-steamers referred to are shown in the following Table:—

	Thyra.	Kjøbenhavn.
Length over stems	177 ft.	274 ft.
Extreme breadth on the frames	26 ft.	34 ft.
" over paddle-boxes	43 ft. 10½ ins.	58 ft.
Moulded depth	12 ft. 9 ins.	16 ft. 9½ ins.
Draught	7 ft. 10 ins.	9 ft. 6 ins.
Load, beside full equipment	76 tons.	225 tons.
Corresponding displacement	580 tons.	1,450 tons.
High-pressure cylinders (No. and diameter) .	One of 32 ins.	Two of 34 ins.
Low " "	" 60 "	" 62 "
Stroke	45 ins.	54 ins.
Diameter of wheel over floats	14 ft. 18 ins.	19 ft.
Working pressure per square inch	80 lbs.	90 lbs.
Number of boilers	Two.	Four.
Heating-surface of boilers (of the common marine type)	2,042	5,704
Highest L.H.P.	652	2,155
Corresponding speed ahead	11·1 knots.	14 knots.
" astern	10·5 "	13·98 knots.
Average speed	9·5 "	12·5 knots.

The Paper is accompanied by nine drawings, from which Plate 6 and the *Fig.* in the text have been prepared.

(*Paper No. 2985.*)

"The Mushkaf-Bolan Railway, Baluchistan, India."

By JAMES RAMSAY, M. Inst. C.E.

THE BOLAN.

THE Bolan Pass has, from time immemorial, formed part of the great trade-route to Afghanistan from the South. It is more than 60 miles long; and, from 450 feet, at its lower entrance, it rises to a height of 6,000 feet above mean sea-level. At this elevation it opens out into the Pishin Plateau, at a spot bearing the inauspicious but well-deserved name of the Dasht-i-bedowlat "the unhappy plain." Many of the hill-peaks near the top of the pass rise to heights between 8,000 feet and 10,000 feet above the sea.

The entrance to the pass from the plains of Sind, about 4 miles west of Dadur, is through the Kundilani Gorge, which is about 20 miles long. This gorge is everywhere surrounded by high hills, and contracts from a width of $\frac{1}{2}$ mile at the lower end until, for a short distance, about half-way, it is less than 200 feet wide; while for a length of some 2 miles the width is never greater than 400 feet, with sheer cliffs of hard limestone conglomerate rising 300 feet to 500 feet above the stream. It gradually widens out to about 1,000 feet, where it opens on to the Lalachi Plain, a dreary waterless waste of limestone boulders and shingle some 25 miles long by about 6 miles wide, which is surrounded by bare, solid limestone hills between 2,000 feet and 5,000 feet high, pierced by deep, narrow clefts, through which storm-waters are poured on to the plain.

The Upper Bolan, from Mach to the summit at Kotal Darwaza, is about 16 miles long. The width of the gap at Mach is 1,000 feet, which suddenly increases to about 1 mile, to contract again below Hirok, about half-way, to little more than $\frac{1}{4}$ mile. The dry bed of the Bolan torrent from Mach to Hirok is some 500 feet wide, cut sheer down to a depth of between 50 feet and 100 feet into the shingle beach which occupies the eastern side of the gorge, the limestone-conglomerate hills rising 1,000 feet to 3,000 feet above it. Hirok is at the lower end of the Dozan Gorge, and

for some miles through this gorge the Bolan occupies a deep and particularly tortuous cleft in the solid limestone rocks, never more than 300 feet, and in some places less than 100 feet wide, the cliffs on each side rising sheer 200 feet and 600 feet above the dry torrent-bed, the surrounding hill-tops being often 3,000 feet and 5,000 feet higher.

The Bolan stream gushes from under the Lalachi Plain a short distance above the upper end of the Kundilani Gorge, so that water always flows in the gorge, and tends somewhat to soften its weird desolation. Although the surface of the Lalachi Plain is furrowed with innumerable dry water-channels of varying depths and widths, it is almost without water, inhabitants, or vegetation, and it is strewn with limestone boulders of every size. At Mach there is always water from springs, but this disappears among the shingle and boulders in the torrent-bed a short distance down-stream; while above Mach there is only one spring in the Bolan Gorge, and its waters almost immediately disappear deep into the shingle.

The difficulties of the Bolan Pass were first recognised when the English Army, marching on Kandahar at the commencement of the Afghan war in February 1839, took ten days in going from Dadur to Quetta, and suffered fearful privations from the inclemency of the weather, as well as from scarcity of water and provisions; while the wretched track over the boulders and shingle in the torrent beds lamed both men and cattle.

In the winter of 1857-8 a survey for a line of railway from Sukkur to Dadur, near the entrance to the Bolan Pass, was commenced by engineers of the old Sind-Punjab and Delhi Railway Company. It was carried from Sukkur through Shikarpur for about 50 miles, when it was stopped, as there seemed no chance of the project being carried out. In 1876 the Government of India ordered a reconnaissance to be made of the passes into Baluchistan. It was reported of the Bolan Pass that its winding narrowness, great acclivity, and number and depth of the ravines leading into it for its whole length, presented many difficulties to the construction of a railway through it, which must of necessity be costly; while the flattest gradient it would be possible to obtain in the upper end being 1 in 20, on curves of 70 feet radii, would cause expensive working, and much time would be needed to seek out a line and construct it to the best advantage. Of the other passes it was reported that, though they presented fewer difficulties than the Bolan, their defiles were frequently narrow and tortuous, and any railway through them would be costly to construct, while leading far distant from the strategic point aimed at.

After the news of the massacre at Cabul in 1879, the Government of India issued orders to lay a line of rails from Ruk to Sibi, at the entrance to the Nari Pass, about 20 miles east from the Bolan. Orders for the collection of the necessary materials from the reserve stocks of all the railways in India were issued on the 10th September, 1879; the first rail was laid at Ruk on the 1st October, and the last rail into Sibi was laid on the 15th January, 1880; thus the 133 miles of broad-gauge railway were laid in three and a half months, or at an average rate of $1\frac{1}{4}$ mile per day.¹ Greater speed would have been made but for the difficulty of feeding and watering three thousand five hundred men and fifteen hundred animals in the middle of a waterless, sandy desert. This line and its extension towards Quetta and Afghanistan were under the direction of Sir Richard Temple, Bart., G.C.S.I., then Governor of Bombay, who, with his engineers, further reconnoitred the Passes; and on their reports the Government of India decided, notwithstanding the extreme reluctance of the Military Authorities, to abandon the old route, *via* the Bolan, for the little-known route *via* the Harnai Valley, because the difficulties on the Harnai route were considered to be far less than those on the Bolan, and military exigencies demanded a line of railway towards Kandahar to be undertaken without delay. This line (known as the Kandahar Railway), of the metre gauge, was commenced at once, and a considerable amount of work was carried out on it, under Colonel James Lindsay, R.E., the Engineer-in-Chief, before it was ordered by the Home Government to be abandoned in 1881.

During 1880 the broad-gauge line was extended west from Sibi to Pir Chowki, at the mouth of the Bolan Pass, a distance of 19 miles, and was found to be of the greatest service in assisting the transport of troops and stores towards Kandahar. Wooden pile bridges were erected across the Nari and Kumbri rivers, but they were sources of great anxiety, owing to their liability to damage from sudden floods. Both were replaced by permanent bridges, which were completed in 1882, the Nari Bridge having seven spans of girders 100 feet in the clear, and the Kumbri three spans of girders 60 feet in the clear, on well-foundations. Rindli, reputed to be the hottest place in the world, $16\frac{1}{2}$ miles from Sibi, was afterwards made the terminus, and extensive sidings for military purposes were laid down.

During the summer season the country along the base of these

¹ Minutes of Proceedings Inst. C.E., vol. lxi. pp. 274 and 286.

hills, and in their lower passes, is almost uninhabitable ; the hot winds blow with a force and a heat beyond description, with the air as dry, hot, and dust-laden as that of a newly-drawn lime-kiln ; and, until the railway staff went there, only the lizard and the hornet dared be abroad. Long before the great heat sets in the Brahui tribes regularly migrate, with their flocks and herds, to the cooler altitudes of the Quetta Plateau, and never return until the commencement of the cold season.

From Rindli a rough cart-track, through the Bolan to Quetta, was constructed by General Phayre, in command of the Bombay Army, during the advance on Kandahar in 1879-80, and was found of great service in facilitating the passage of troops and military stores through this dreaded locality. It was afterwards handed over to the Royal Engineers of the Military Works Department, who, by their skill in alterations and improvements, carried out at intervals up to a recent date, have converted it into a road fit for wheeled traffic of every description, certain to prove of immense assistance when military operations are again undertaken beyond the frontier. It is metalled and bridged throughout, and, being scarped out along the cliffs well above the reach of the Bolan floods, is not liable to damage, except in a few localities from hill-side slips, which can, however, be speedily repaired. In the Kundilani Gorge there is a short tunnel through a spur of the conglomerate cliffs, and close by is a wrought-iron girder bridge, 200 feet in the clear, completely spanning the chasm.

In 1883 the Government decided to resume the abandoned works in the Harnai Valley as a military road, and the late Colonel Browne, C.S.I., (afterwards Major-General Sir James Browne, K.C.S.I., C.B., R.E.), was appointed Engineer-in-Chief, with a staff of Royal Engineers. Considerable progress was made with the works before it was decided, in 1884, to extend the broad-gauge railway from Sibi up the Harnai Valley to the Pishin Plateau, under the name of the Sind-Pishin State Railway. The staff had to be augmented by Civil Engineers, and, platelaying being vigorously proceeded with, the rails (which for considerable distances were laid along the bed of the Nari river) reached a point about 20 miles north from Sibi, when, early in 1885, an abnormal flood, or what was then considered to be such, caused immense and costly damage by wiping out the line for miles ; so that, when the Author joined it as Superintending Engineer, the locomotives could only run to about 10 miles from Sibi. A succession of floods during the spring and summer greatly interfered with the works, especially at the numerous large

bridges over the Nari river; but by April the material trains were regularly worked on the permanent formation to the twentieth mile from Sibi, the temporary line in the river-bed being lifted. Unfortunately all work on this lower length had to be completely closed and the staff dispersed in May, 1885, owing to the outbreak of a terrible cholera epidemic which carried off the native work-people in hundreds, and it was not until the middle of September that work could be resumed.

After the Panjdeh incident, the Government of India determined to have speedier railway communication with Quetta than the Sind-Pishin Railway (Harnai route) promised to afford. It was, therefore, decided to lay a temporary surface broad-gauge line rapidly up the Bolan Pass, the work being entrusted to Colonel James Lindsay, R.E., as Engineer-in-Chief, who commenced operations at Rindli (440 feet above sea-level) in April, 1885. The season proved most unfavourable, and a fearful epidemic of cholera breaking out, which carried off both Europeans and coolies, the work was practically stopped after some 8 miles of rails had been laid. Mr. F. L. O'Callaghan, M. Inst. C.E., C.I.E., succeeded Colonel Lindsay in June, 1885, and, by great exertions and exposure on the part of the staff, the line to Hirok (4,600 feet above sea-level), about 50 miles from Rindli, was completed on the 19th November of the same year. The permanent way was laid in the Bolan torrent-bed, crossing and recrossing the water-channels incessantly on 10-foot span openings formed of crib-piers made from wooden sleepers. Owing to their liability to be underscoured by freshets, the maintenance of these innumerable crib-piers was found to be so troublesome and expensive, that they were soon largely removed, and the permanent way was laid on the shingle, so that trains were safer, even though they were frequently running through swiftly flowing water, 12 or 15 inches above the rails, when crossing the bends of the water-channel in the Kundilani Gorge. The permanent way consisted of 75-lb. steel rails on cast-iron sleepers (Denham-Olpherts pattern), and 80-lb. and 68-lb. old iron rails, with cast-iron chairs on wooden sleepers. The ruling gradient for the first 35 miles was 1 in 40 (2·5 per cent.), then about 8 miles of 1 in 30 (3·3 per cent.), and for about 7 miles the gradient was 1 in 25 (4 per cent.), the minimum radius of curves being 800 feet ($7^{\circ} 10'$).¹

During this time the works for a temporary metre-gauge line

¹ The angles are those subtended at the centre of curvature by a chord of 100 feet.

about 9 miles long, through the Upper Bolan, from Hirok to Kolpur (Kotal¹ Darwaza), 5,900 feet above sea-level, were actively proceeded with, as well as those for the broad-gauge permanent line from Kolpur (Kotal Darwaza) to Quetta (5,500 feet above sea-level), a length of 25 miles. As soon as the materials could be brought up to Hirok for it, the metre-gauge line was laid in the Bolan torrent-bed, following the tortuous windings through the narrow Dozan Gorge. The permanent way used was old broad-gauge double-headed iron rails, weighing 80 lbs. and 68 lbs. per yard, with cast-iron chairs on broad-gauge wooden sleepers. The ruling gradient was 1 in 23 (4·35 per cent.), the sharpest curve being about 200 feet radius ($28^{\circ} 30'$), and the line was opened for traffic in March, 1886. It was worked with Fairlie locomotives. The works from Kolpur (Kotal Darwaza) to Quetta were all of a permanent character; the ruling gradient is 1 in 100 (1 per cent.), laid with flat-footed steel rails weighing 75 lbs. per yard, on steel transverse trough sleepers to the 5-foot 6-inch gauge; and the line was opened for traffic in August, 1886, when Mr. O'Callaghan's connection with it ceased. Extensive arrangements were in use for transhipping materials from the broad to the metre gauge at Hirok, and at Kolpur (Kotal Darwaza) from the metre to the broad gauge.

This Bolan Railway justified its construction by its political effect after the Panjdeh incident, and the assistance it gave towards enabling the Sind-Pishin Railway (Harnai route) to be opened for traffic more than twelve months sooner than it could have been otherwise. Owing to the comparative immunity from damage by floods, enjoyed by the Bolan Railway during the first two years of its existence, the authorities were beguiled into thinking it could be maintained as a permanent means of communication with the Pishin Plateau; and a proposition was made, in 1887, to construct a high-level line from Hirok to Kolpur, with a ruling gradient of 1 in 23 (4·35 per cent.), in place of the metre-gauge line in the bed of the ravine, to give through communication with Quetta on the standard gauge, and do away with the expensive transhipping arrangements in use at Hirok and Kolpur. This was sanctioned by the Government of India, and the opportunity was taken to enquire into the working of the Abt rack system of traction, resulting in some 5 miles of this system of permanent way, and two locomotives, being ordered from Messrs. Rinecker & Co. In 1888-9 about 1 mile of this was laid, above Hirok, for experimental purposes with the locomotives; but an un-

¹ Kotal, meaning the summit of a pass.

favourable report was the result, and the racks were stacked at Hirok, the locomotives being sent to the workshops.

On this so-called "high-level" line the works in some places were heavy, and there was one short tunnel; but the line was kept at too low levels through the ravine, and economy was carried to the verge of recklessness, by fitting the waterways across the gorges to suit a limited quantity of old metre-gauge materials. It had hardly been passed as fit for traffic, in the summer of 1889, when heavy rains among the surrounding high hills caused a severe flood down the gorges, which did great damage not only to the "high-level" line, but also to the line laid along the torrent-bed below Hirok, as far as Rindli. About the same time the Sind-Pishin Railway (Harnai route) suffered very great damage from a flood due to still heavier rains in that locality, and railway communication with the Quetta garrison was completely suspended.

At the end of 1889, the Author took charge of the Sind-Pishin and Bolan Railways as Engineer-in-Chief, and reconstruction work was vigorously undertaken. The lower lengths of the Bolan (Quetta Loop it was called officially) were rapidly repaired, and the upper length was strengthened, and some of the waterways lengthened. Late in the summer of 1890 a heavy rainfall among the hills above Hirok caused another and still more destructive flood in the Bolan, which completely wrecked the line in the Dozan Gorge, buried some of the bridges under heaps of shingle, carried away many of the others without leaving a vestige behind, and seriously damaged the masonry piers and abutments of the remainder; while, below Hirok and Mach, and at the Kundilani Gorge, all traces of the line were completely obliterated for miles.

When rain does fall in these arid regions of high, bare, limestone hills, the water acquires high velocity in rushing down the precipitous gorges with which their steep sides are cleft; and, though the volume of water may not be very great, the steep declivities give extraordinary impulse and force to the floods during the short time they last. It was stated, by an eye-witness of the flood of 1890, that the roar from the boulders being trundled along the torrent-bed in the Dozan Gorge was deafening; and, although the water was not more than 1 foot or 2 feet deep, so great was the speed with which the boulders were hurled at obstructions that the cutwaters of the stone piers, at the few bridges left standing, were battered out of shape to heights of more than 10 feet above the torrent-bed. Huge boulders weighing many tons each were, at the same time, carried considerable distances. This flood settled the question of through communication on this so-

called "high-level" line, and gave the engineers many most useful lessons in mountain engineering.

The great difficulty and expense experienced, during blinding blizzards of both snow and hail, in repairing the Sind-Pishin Railway (Harnai route), and the cost and uncertainty of its upkeep and regular working, strengthened the determination of the Government of India to have another, and, if possible, reliable railway to Quetta; that place being the great military cantonment on the North-West frontier, of immense strategic importance, with its lines of invulnerable fortifications extending for miles on the hill-sides, all constructed and armed in accordance with the latest scientific military principles.

THE MUSHKAF-BOLAN.

During the construction of the temporary railway in the Bolan Pass, in 1885-86, Mr. F. L. O'Callaghan examined into and reported on the practicability of constructing a permanent railway by this route to the plateau. A preliminary survey was made for a line by way of the Mushkaf Valley with a ruling gradient of 1 in 40 (2·5 per cent.) throughout, and the works were estimated to cost Rs.165,00,000. This project was submitted to the Government of India in September 1886, but for various reasons it was not proceeded with.

In November 1890, the detailed surveys for the new railway were entrusted by the Government of India to the Author, in addition to his other duties, with instructions to submit plans and estimates for the provision of a safe line of communication between India and the Baluchistan Plateau, which would be more reliable than the existing lines, out of reach of the Bolan floods throughout, and free from land-slides and similar interruptions to traffic. It was not deemed necessary to further consider the route *via* the Kundilani Gorge, as that was very intimately known, and had already been reported on; so that the thorough study of the less-known Mushkaf Valley was decided on, for getting the stable line required. The preliminary plans above mentioned were of much assistance to the staff in selecting the line ultimately adopted. It was seen that the Mushkaf river is 200 feet higher than the Bolan, at the point where they are divided from each other by a high though narrow range of limestone hills, 26 miles from Sibi, and this neighbourhood was considered to be the key to the route. The original plans showed a reverse gradient of

1 in 50 (2 per cent.), with very heavy works, for $2\frac{1}{2}$ miles down into the Bolan Valley (28 miles from Sibi); and, unless this could be flattened to 1 in 100 (1 per cent.), or to 1 in 80 (1·25 per cent.), at the steepest, either costly and troublesome siding arrangements would have to be made, at both top and bottom, for changing the positions of the engines of all double-engine trains before commencing the descent or ascent, according to the direction in which they might be working, or this route might have to be abandoned. To determine this, a series of careful trial lines were run over this extremely difficult piece of country, and it was eventually found that 1 in 100 (1 per cent.) could be substituted for the 1 in 50 (2 per cent.), by facing some additional very heavy works, with an extra tunnel through a spur from the main range, and keeping at higher levels on the hill-slopes along the Bolan Valley. Estimates, amounting to Rs.137,17,565, with completed plans and sections for the construction of the new railway, $56\frac{1}{2}$ miles of single line of 5-foot 6-inch gauge, were submitted to Government in September 1891; and were sanctioned in November, with orders for the works to be commenced at once, the Author being appointed Engineer-in-Chief, and relieved from the charge of the Sind-Pishin (Harnai route) open line; and, there can be no doubt, had the works not been starved for want of funds, this new railway could have been finished in the spring of 1894. The old Bolan Railway was included in this charge, with orders that it was to be so far kept open as to be available for military purposes, if required.

As the Khojak Tunnel through the Kwaja Amran range, between Quetta and Kandahar, had just been completed, the opportunity was seized of securing a large quantity of the tunnelling machinery, and other plant for the Mushkaf-Bolan Railway; so that a good start was made during the working season 1891–92, with the crowds of people flocking to the works from Hazara and Afghanistan generally. At the same time, a line of telegraph was commenced to connect the head office with the different district offices; some changes were made for improving the old Bolan Railway by taking it out of the torrent-bed below Mach on to a new alignment, where, for some 8 miles or 9 miles, it was safe from floods; and the rails were placed lower in the shingle, at the numerous "dips" crossing the river-channel in the Kundilani Gorge, so that, at these places, trains were running through swiftly flowing water of greater depths than before, with the great advantage that the permanent way was much less liable to damage from ordinary freshets.

As the Government also determined that all the tunnels and the masonry of all the bridges were to be built for a double line throughout, some alterations in the alignment had to be made, especially in the Upper Bolan, which increased the length of the new railway to 58·75 miles. Revised estimates had therefore to be prepared to include the new works, and were sanctioned, amounting to Rs.2,00,85,470, being at the rate of Rs.3,38,088 per mile.

The Mushkaf Valley is nearly as long as the Bolan, but its drainage-area is much smaller, and its declivity less severe. Though it is, perhaps, even more dreary, weird, and desolate than the Bolan, it is nowhere so wide, nor are its gorges so deep. The width is seldom more than about $\frac{1}{4}$ mile for short distances; and, except near its head-waters, the geological formation is soft sandstone with layers of green and red clays, and occasional patches of limestone boulder conglomerate. There is in the Mushkaf valley hardly any stone fit for bridge-building.

The Mushkaf-Bolan Railway, Figs. 1 and 2, Plate 7, runs for about 5 miles from Sibi (433 feet above sea-level) on the old Bolan Railway formation, across the Nari river to the new Nari Bank station, where the new works commence, and, curving to the right, traverses an open sandy plain to the Mushkaf Gorge, 12 miles from Sibi, and 520 feet above sea-level. From here, the country traversed by the new railway may be divided into three well-defined sections, having distinctly different local features. The first 18 miles are cut through very rough country, with numerous high rocky spurs requiring fourteen tunnels, cuttings more than 70 feet deep, and a few embankments 90 feet or 100 feet high. The next 16 miles are over an open waterless country, strewn with boulders of all shapes and sizes, requiring an abnormal number of bridges to pass the storm-waters that occasionally pour down the numerous gorges by which the steep sloping hill-sides are deeply scored, and if checked would simply overwhelm the line with masses of rocks and boulders. The upper 16 miles are in a wild country of high, bare, limestone rocks, where the hills rise to heights of between 6,000 feet and 10,000 feet above sea-level, necessitating the construction of six tunnels, heavy earthworks both in cuttings and embankments, and expensive special bridging across the deep tortuous channels cut by the Bolan torrents.

The railway enters the Mushkaf Gorge, which is only about 400 feet wide, through a tunnel 470 feet long; then passes boldly across a bend of the river on two large bridges, and five tunnels through the numerous saw-toothed soft sandstone spurs, these

heavy works extending over about $1\frac{1}{2}$ mile. The principal works are shown in the following Table :—

Tunnel No. 1	470 feet long.
Mushkaf Bridge (first crossing) . . .	{ Three girder spans 150 feet in clear, and four arches 30 feet span.
Tunnel No. 2	650 feet long.
Tunnel No. 3	366 feet long.
Tunnel No. 4	527 feet long.
Mushkaf Bridge (second crossing) . . .	{ Three girder spans 150 feet in clear, and two girder spans 60 feet in clear.
Tunnel No. 5	353 feet long.
Tunnel No. 6	211 feet long.

These tunnels are through layers of soft sandstone alternating with bands of indurated clay, most treacherous materials to deal with, as the clay, though extremely hard and troublesome to blast while *in situ*, becomes very friable when exposed to the air, and falls down in great masses with but little warning. Heavy timbering was necessary throughout, and the enlarging and arching had to proceed simultaneously, with English miners to overlook the native work-people. All are three-quarter lined with brick masonry in Portland-cement mortar. At Ocepur station (982 feet above sea-level), $1\frac{1}{2}$ miles from Sibi, the railway again crosses the Mushkaf river, in a deep gorge cut down through limestone conglomerate, on a girder bridge of 200 feet clear span; thence, after traversing a number of ravines and passing through two tunnels, the Mushkaf river is crossed for the fourth time, and about 1 mile further on is Panir station, 1,411 feet above sea-level and $26\frac{1}{2}$ miles from Sibi. The principal works on this length are :—

Mushkaf Bridge (third crossing) . . .	{ One girder span 200 feet in clear.
Bridge No. 39	{ One girder span 60 feet in clear.
Tunnel No. 7	739 feet long.
Tunnel No. 8	306 feet long.
Mushkaf Bridge (fourth crossing) . . .	{ Four girder spans 100 feet in clear.

Tunnels Nos. 7 and 8 are through the high cliffs along the left bank of the Mushkaf river, in conglomerate with occasional claybands, and are three-quarter lined with brick masonry. They were excavated for the most part by means of short horizontal adits run in from the cliff faces.

As there is practically no water in the lower Mushkaf Valley, advantage was taken of some springs near Tunnel No. 7 to build a collecting sump, from which water was conveyed by gravity for about 12 miles through 4-inch wrought-iron piping, and was

distributed to the various works in pipes of smaller diameter, the total fall in the 12 miles being 650 feet. A temporary railway was laid from Nari Bank station to the southern or Sibi end of the Panir Tunnel, for the conveyance of materials by rail to the neighbourhood of the various bridges and tunnels, and proved of the greatest assistance in pushing on the works. Its gradients in the Mushkaf Gorge were stiff, and a short length of 1 in 25 was necessary to avoid expensive works in rising out of the gorge.

About 1 mile beyond Panir station, and 27 miles from Sibi, the longest tunnel on this railway occurs. It passes through Panir Bund, the narrow range of hills dividing the Mushkaf from the Bolan Valley. The Panir Tunnel (1,468 feet above sea-level) was originally proposed to be 3,000 feet long, but, owing to rotten sandstone with red clay being met with at the Sibi end, it has since been lengthened by 218 feet. Work was commenced upon it in November 1892; the headings met in August 1893; the average rate of progress working out to 13 lineal feet per day; and the tunnel was completed in August 1895, native labour only having been employed on its construction. It traverses for the most part nummulitic limestone of varying quality, so that the extent of lining varies accordingly, being in some places three-quarter lined, while in others it is only one-half or quarter lined. The roofs of the tunnels are all lined, as it has been found that the atmosphere and products of combustion from locomotives exercise injuriously disintegrating effects on even the hardest rocks in unlined tunnels, causing pieces to fall from the roofs and sides, thus endangering the safety of trains. This is the only tunnel at which machine-drills, worked by compressed air, were extensively used. The air-compressing plant was erected on the Bolan side of the hill, and while the compressed air was supplied to the Bolan heading, which was the one principally worked, it was also conveyed to the Sibi heading by a separate line of 4½-inch wrought-iron pipes, about 6,500 feet long, laid over the Panir hill, the summit of which rises 1,000 feet above the tunnel. Both Schram and Climax machine-drills were used. The latter was found more suitable for the hard strata, and its simplicity better fitted it for the native labour, though excellent work was accomplished with the Schram drills in the softer strata. In the widening out, the machine-drills were superseded by hand labour which was found to be cheaper.

These works were connected with the railway system, on the Sibi side, by the temporary railway from the Nari Bank station already mentioned. On the Bolan side a temporary branch, 5 miles long, was laid across the Lalachi Plain from the old Bolan Railway, a

short distance above the upper end of the Kundilani Gorge, to the foot of the Panir hill, for the conveyance of materials and stores by train. As the tunnel is 200 feet above the Bolan river, all building and other materials were conveyed to the sites of works on two metre-gauge inclined planes, which were constructed from the broad-gauge branch up to the tunnel entrance. These were on the three-rail system, that is, with the central rail common to both lines, and with passing sidings half-way where the ascending and descending trucks passed each other, so that the steel ropes never crossed the rails. The lower incline was 2,000 feet long, with gradients rising on 1 in 25 (4 per cent.), and 1 in 10 (10 per cent.), while the upper incline (which was longer in use than the lower) was 375 feet long, on a gradient of 1 in 2½ (40 per cent.) throughout. Each incline was worked by its own winding-engine, and the upper incline had two special trucks, so constructed, on wheels of different diameters, that the platforms with their pairs of metre-gauge rails were always horizontal during transit. The material wagons were carried on the tops of these incline-trucks, being shunted on at the bottom and off at the top, and *vice versa*. The whole was improvised from various old materials on hand, and worked satisfactorily without accident. There being no water in the Bolan channel at this neighbourhood, the water-supply to this tunnel, as well as to the heavy works for about 4 miles into the Bolan Valley, had to be obtained from some springs near Bibinani, being brought by gravity through a line of 4½-inch wrought-iron piping, 7 miles long, and distributed, in different directions, through many more miles of branch-piping of smaller diameters.

The country for the 2½ miles between the Panir and the Seetul Tunnels, leading down into the Bolan Valley, is of the roughest and most difficult description. No conception of its roughness and difficulties could be formed from an inspection of the centre-line section, though that shows a succession of tunnels, deep cuttings, and high embankments (notably No. 29, which is 95 feet high for about ¼ mile, and contains more than 378,000 cubic yards of earth-work), while one gorge is a narrow cleft 100 feet wide by 150 feet deep. The girders (of 150 feet clear span) now spanning this gorge were hoisted from below in pieces, built close to site, and were then run out on wire ropes stretched across the cleft over a derrick, which could be inclined to bring the girders into their positions. This bridge is on a curve of 1,433 feet radius (4°). The general inclinations of the hill-sides range between 1 to 1 and 3 to 1; and it was along "goat-paths" cut on them that the bricks and cement, and other materials, had to be carried to the works on

donkeys; while the wheelbarrows, metre-gauge trucks, and timber had to be carried on men's backs, along places where a false step meant falling to depths of 100 feet or 200 feet.

The strata of these hills are chiefly nummulitic limestone; but in places there are layers of red and green clays lying at steep inclinations under the rock, which gave much trouble both in the tunnels and cuttings, requiring the former to be heavily timbered and fully lined, and breast-walls to sustain the slopes of the latter. The principal works on this length are :—

Tunnel No. 10	319 feet long.
Tunnel No. 11	417 feet long.
Bridge No. 63	{ One girder span 150 feet in the clear.
Bridge No. 64	{ One girder span 60 feet in the clear.
Tunnel No. 11a	550 feet long.
Tunnel No. 11b	150 feet long.
Dhoki Bridge	Three arches 30 feet span.
Seetul Bridge	Three arches 30 feet span.
Seetul Tunnel (No. 12)	1,025 feet long.

The Seetul Tunnel (1,406 feet above sea-level), through limestone conglomerate, is 30½ miles from Sibi, and from here to Ab-i-gum station (2,157 feet above sea-level), 39½ miles from Sibi, the railway winds along the slopes of the hills skirting the eastern edge of the stony Lalachi Plain, on an almost continuous embankment. The bridges are exceptionally numerous, and nearly every one of them required different treatment in regard to details of design, as well as in regard to the special training-works necessary to suit the localities, and induce the floods to use them. Close observation can alone qualify for successful construction in these hilly countries, as the application of any formulas to determine the waterways required in them, even when the rainfall is known, is delusive. Many of the training-works extend for long distances from the bridges, and are of solid masonry walling, or a combination of masonry and concrete walling, the numerous retaining-walls being of similar construction. Experience in the re-construction of the Sind-Pishin Railway (Harnai route) showed that only solid masonry, deep founded, can resist the scouring force of the floods. The *talus* across which the new railway runs is very steep in places, and the floods move enormous masses of gravel and boulders, which, if checked by narrow outlets, would simply pile up against the obstacles and bury or overwhelm them by sheer weight of material. All openings of and under 20 feet span have deep drop-walls built from abutment to abutment, both up and down stream, with flooring between (laid in mortar) 4 or more feet below the

natural level of stream-beds, at inclinations varying between 1 in 5 and 1 in 10, according to the locality; and it is expected these precautions will prevent back-scouring from the down-stream sides. Between Chidderzee and Ab-i-gum stations, 3½ miles, the railway turns across the Lalachi Plain, over so many ill-defined water-courses that a long viaduct of twenty girder spans 60 feet in the clear, and numerous smaller openings aggregating some 500 lineal feet of waterway, are not considered too much to ensure its safety. The Pishi station is 31 miles, and the Chidderzee station 36 miles, from Sibi, their respective heights above sea-level being 1,458 feet, and 1,865 feet. About 1 mile from Pishi and 1½ mile from Chidderzee stations, are some small springs whose waters are collected into sumps, for supplying the stations by gravity through wrought-iron pipes; and, as a temporary arrangement, the water was distributed to the works by gravity for long distances, the district being a desolation of limestone boulders, and shingle, practically waterless. To the works in the neighbourhood of Ab-i-gum station water was led by gravity, through wrought-iron pipes laid deep across the Bolan channel, from a place nearly 4 miles distant.

Between Sibi and Ab-i-gum the ruling gradient is 1 in 55 (1·81 per cent.), compensated for curvature, the sharpest curvature being 1,011 feet radius ($5^{\circ} 40'$), which has only been allowed where flatter curvatures would have increased the cost of the works abnormally. The general rise is continuous, with the exception already mentioned, of the undulation between the Panir and Seetul tunnels, which, however, is unavoidable, owing to the difference of level between the Mushkaf and the Bolan Valleys. Between Ab-i-gum and Mach stations, a length of 7 miles, the ruling gradient is 1 in 33·3 (3 per cent.), compensated for curvature; and as the general slope of this upper part of the Lalachi Plain varies between 1 in 40 (2·5 per cent.) and 1 in 25 (4 per cent.), a tortuous alignment was obligatory to get so flat a gradient as 1 in 33·3 (3 per cent.). Over this length the railway is on a continuous low embankment with but few culverts, though the plain is furrowed by numerous dry watercourses. Many of these, however, have been judiciously cut into each other, thus concentrating the drainage at the places where provision has been made for passing it. It may be mentioned that the foundations of all embankments are soled, from toe to toe, with layers of boulders, hand-laid, between 15 and 30 inches high, according to their heights and the wealth of their neighbourhoods in boulders. This method facilitates the drainage, by preventing water lodging along the up-stream toes of embankments.

The site selected for the Mach engine-changing station is on the bare stony plateau overlooking the Bolan, but 100 feet above the torrent bed, and 2 miles down-stream from Old Mach. It is 3,246 feet above sea-level, $46\frac{1}{2}$ miles from Sibi; and owing to the slope of the ground at the confined space available being 1 in 40, it is laid out as a "reversing" station, so that the rear ends of trains entering it become the leading ends when leaving it. By this arrangement ample siding accommodation is enabled to be provided, on the level, for both traffic and locomotive purposes, and more compactly than could be done at this place by any other.¹ The special engines for working trains over the steep gradients will be stationed here, and there have been built a large station and offices, a commodious engine-shed complete in all requirements, numerous houses for the employees, as well as a large masonry tank capable of holding 120,000 gallons, the water being led into it by gravity, through wrought-iron piping, from springs opposite Old Mach, about $2\frac{1}{2}$ miles up the valley.

The "Upper Bolan" extends from Mach to Kolpur, a length of $15\frac{1}{2}$ miles, the vertical rise being 2,628 feet, almost $\frac{1}{2}$ mile. The ruling gradient is 1 in 25 (4 per cent.), of which there are 12 miles practically continuous out of the $15\frac{1}{2}$ miles. The 8 miles from Mach to Hirok (4,652 feet above sea-level, and $54\frac{1}{2}$ miles from Sibi) are over an open shingle beach 60 feet to 80 feet above the Bolan torrent, on light works, except for the mile in the Mach gap, where there are some large cuttings through very compact limestone conglomerate, and a bridge, 65 feet high, across the Hannar Nulla just above its junction with the Bolan. The piers of this bridge, spaced at 160 feet centres, are of very massive stone masonry, and, to deflect the furious Bolan floods past the bridge, extensive protective walling has been built in the neighbourhood of both abutments, with, in addition, a high, specially strong masonry groyne near the north abutment. The principal works on this 8-mile length are:—

Hannar Nulla Bridge	{ Two girder spans 150 feet in the clear; one girder span 100 feet in the clear; one girder span 60 feet in the clear.
Sir-i-Bolan Tunnel (No. 13)	335 feet long.
Bridge No. 194	{ One girder span 40 feet in the clear.
Bridge No. 197	{ Three girder spans 60 feet in the clear.

¹ It has been found convenient to carry the line straight through Mach without using the "reversing" station.

The general slope of the Bolan torrent-bed between Mach and Hirok is 1 in 25, and the old Bolan Railway was originally laid along it; but, this being one of the localities most liable to severe damage by floods, the permanent way was taken up and laid on the new formation in the summer of 1892, and connected with the old railway from the dip in front of the Hannar Nulla Bridge by a temporary "zigzag" on 1 in 25 (4 per cent.) gradients, the vertical rise being 160 feet in about $\frac{1}{2}$ mile. By these means the length of temporary line subject to flood damage in this neighbourhood was reduced to about 1 mile, and the transport of material was satisfactorily worked over the "zigzag" until the Hannar Nulla Bridge was completed. It should be mentioned that the old Bolan Railway between the upper end of the Kundilani Gorge and Mach was closed in the summer of 1893, when the materials were lifted and laid on a temporary alignment parallel to the permanent works from Panir to Mach, so that, except between Sibi and the upper end of the Kundilani Gorge, there was nothing left of the old Bolan Railway, which, however, had proved useful, if not indispensable, to the new works.

Hirok, noted for its bleakness, is situated on a bare wind-swept boulder slope, and from it to the summit at Kolpur (5,874 feet above sea-level, and 62 miles from Sibi), a length of $7\frac{1}{2}$ miles, the works are exceptionally heavy, being a succession of deep cuttings, tunnels, high embankments (often supported by massive retaining walls), and large bridges in diverse styles of construction. The defile in the Dozan Gorge, about 6 miles long, is so narrow and tortuous, and so confined between high vertical cliffs, that the new railway is forced to cross and re-cross it nine times in 4 miles, the bridge design for each crossing having to be specially considered to suit it to the varied conditions of site. The general slope of the torrent-bed in the gorge is between 1 in 20 and 1 in 23, becoming flatter, however, towards the upper end. The new formation throughout is high above the floods, being, in fact, mostly 20 feet above the old so-called "high-level" line. The bridges are built with massive limestone masonry in Portland cement mortar; and, where piers in the torrent-bed are unavoidable, they have been constructed parallel to the axis of the torrent, the cutwaters of some being like those on Canadian railways for parting ice floes. Many of these bridges cross at very acute angles, and some are on reverse curves. The principal works on the $7\frac{1}{2}$ miles between Hirok and the summit at Kolpur station are:—

Dherok Nulla Bridge (No. 204)	{ Four girder spans 60 feet in the clear.
* Pir Panjah Bridge (No. 210)	{ One girder span 150 feet in the clear, three spans of 30-foot arches.
Tunnel No. 13a	200 feet long.
Cascade Bridge (No. 211)	{ Three girder spans 60 feet in the clear.
Cascade Tunnel (No. 14)	542 feet long.
* Elgin Bridge (No. 213)	{ One girder span 150 feet in the clear; four arches of 30 feet span.
* Bridge No. 214	{ Two girder spans 100 feet in the clear, and two girder spans 40 feet in the clear.
* Bridge No. 215	{ Two girder spans 100 feet in the clear, and one girder span 60 feet in the clear.
* Crux Bridge (No. 216)	{ Four girder spans 60 feet in the clear.
Windy Corner Tunnel (No. 15)	406 feet long.
* Dozan Bridge (No. 221)	{ Two girder spans 100 feet in the clear.
* Bridge No. 233	{ Two girder spans 150 feet in the clear, one girder span 60 feet in the clear.
Mary Jane Tunnel (No. 16)	581 feet long.
* Bridge No. 236	{ Four girder spans 60 feet in the clear.
Sangani Bridge (No. 241)	{ Five girder spans 40 feet in the clear.
* Ninth and Last Bolan Bridge (No. 243)	{ Seven girder spans 40 feet in the clear.
Bridge No. 246	{ Two girder spans 40 feet in the clear.
Bridge No. 250	{ Four girder spans 40 feet in the clear.
Summit Tunnel (No. 16a)	315 feet long.

The bridges marked * are over the Bolan torrent, and five of them, viz., Nos. 210, 213, 214, 215, and 216, occur on the same mile, No. 214 being on a curve of 900 feet radius ($6^{\circ} 25'$), the sharpest curvature on the railway, and No. 216 on a curve of 955 feet (6°) radius. Tunnel No. 14 is through a cliff of hard, blue limestone, and some light Ingersoll machine-drills were used in driving the top headings. Tunnel No. 15 is on the 955 feet curve, being the only curved tunnel in the Upper Bolan. It is through a spur of brecciated limestone, which proved very dangerous to work in, and required to be very heavily timbered under the supervision of English miners. As the declivities of the small side ravines range between 1 in 3 and

1 in 10, the arching, where arched culverts are built, is in steps at inclinations of 1 in 20. The new works extend for about $1\frac{1}{2}$ miles beyond Kolpur, which is an engine-changing station, provided with convenient siding accommodation, an engine-shed, turntable, &c., as the special locomotives for working over the steep gradients will stop here, and trains will be worked to and from Quetta (5,500 feet above sea-level), 25 miles distant, by ordinary locomotives, the ruling gradient being 1 in 100 (1 per cent.). The Dozan station (5,161 feet above sea-level) is on a level "back-shunt" $57\frac{1}{2}$ miles from Sibi, and about half-way between Hirok and Kolpur. Water is brought to this station in wrought-iron pipes from some springs about 2 miles away among the hills, going by gravity to Hirok, and is pumped up to Kolpur station, where a tank of 100,000 gallons capacity has been built.

This being a military railway, on which, in the event of war, the safety of the army may depend, it seemed to the Author essential that the four-wheeled rolling-stock with 16-foot wheel-base from all the broad-gauge railways in India should be able to use it with safety, and he endeavoured to make the limiting radius of curvature 1,011·5 feet ($5^{\circ} 40'$), and even to use this as seldom as possible; but in the Dozan Gorge, so exceptionally narrow and tortuous, one curve of 900 feet radius ($6^{\circ} 22'$), and another of 955 feet radius (6°), already mentioned, are unavoidable for safe work. With guard-rails laid along them, they will prove no hindrance to the passage of the long wheel-base four-wheeled rolling-stock from all India. The most frequent curvature on the railway is of 1,433 feet radius (4°). Owing to the curves of 600 feet to 800 feet radii ($9^{\circ} 33'$ and $7^{\circ} 10'$) scattered over the whole length of the undulating Sind-Pishin Railway (Harnai route) on its nominal 1 in 40 (2·5 per cent.) gradients, considerable transhipping is necessary at Sibi, from four-wheeled wagons with 16-foot wheel-base into the bogie-wagons which are mostly used on the frontier railways. It has been found that the curve resistance of a train composed of bogie-wagons is greater than that offered by a train composed of four-wheeled wagons.

The ruling gradients on the new railway are:—1 in 55 (1·81 per cent.) from Sibi to Ab-i-gum, $39\frac{1}{2}$ miles; 1 in $33\cdot3$ (3 per cent.) from Ab-i-gum to Mach, 7 miles; and 1 in 25 (4 per cent.) from Mach to Kolpur, $15\frac{1}{2}$ miles, and on all curves the ruling gradients have been "compensated" or flattened, the compensation adopted being 0·05 per degree (central angle) of curvature, so that the ruling gradients are actual and not nominal. The very steep gradients have been "bunched" on the $22\frac{1}{2}$ miles length between Ab-i-gum

and Kolpur, for convenience of working with auxiliary engines, and vertical curves have been introduced to ease all important changes of gradient. Five catch-sidings, with gradients rising to 1 in 5 (20 per cent.), have been made on this length, mostly just above the stations, to stop runaway trains, and be checks on the speeds of all descending trains. As their points will always be locked for the catch-sidings, each descending train must stop dead before they are opened for its passage onwards. All the stations have been made defensible, with their walls loopholed for musketry, and the water-towers form part of the buildings. There are in all thirteen stations, and they are built at convenient distances apart to facilitate working the traffic of a single line; but some of them, notably Bohr Hill, Sir-i-Bolan, and Dozan, will probably be converted into mere "signal-stations" for their catch-sidings, after a double line is laid. Each station has two 8-inch diameter water-columns between the lines.

In the Mushkaf Valley all the masonry is of brickwork in Portland-cement mortar. Twenty-nine millions of bricks were manufactured near Sibi, where kilns were built immediately after sanction was received to start the new railway works; but, the supply of coal-dust from the local coal-mines near Khost, on the Sind-Pishin Railway, proved inadequate, and the moulders, who were all specially imported from the Punjab, being difficult to keep, 11 millions had to be manufactured at and transported from Jacobabad, where there is abundance of wood-fuel and labour. All bricks were required to be burned specially hard, to withstand the action of the magnesian and other salts with which the soil is impregnated. The masonry in the Bolan Valley is built with stone in Portland-cement mortar, excepting the arching, which is all of brickwork. The ratio of sand to cement is between 4 to 1 and 6 to 1, and in some instances 7 of sand was used to 1 of cement. The concrete, both in foundations and in retaining walls, was composed of 1 cement, 4 sand, and 6 of shingle and broken stone (in equal parts), with large rubble-stones placed at intervals throughout the work. All the Portland-cement was imported from England, and 194,244 barrels were used. About 45 miles of wrought-iron piping, of diameters between $4\frac{1}{2}$ inches and $1\frac{1}{2}$ inches, were in use for supplying and distributing water, by gravity, to these works. The explosives used were dynamite, gelignite, nitro-glycerine, and European and native blasting powders. A temporary manufactory for the latter was established near Mach, at which considerable quantities were produced. About 80 tons of dynamite were used on the works.

The tunnels and their entrance cuttings are all made for the double line; and, wherever it was possible to utilize the material in them, the opportunity was taken to make other cuttings to the double line width also. The widths of the tunnels are between 29½ feet on the straight, and 33 feet according to the radius of the curve on which each occurs. Most of them are, however, on the straight.

The girders for the bridges are of steel, and are designed to carry specially heavy engines. The roadway is on the top booms, with corrugated plates for supporting the ballast and permanent way, the line being laid on ballast throughout. The weight of the girder-work is 7,438 tons. The ballast is gravel and small shingle throughout. From Sibi to Ab-i-gum it is 18 inches, and from Ab-i-gum to Kolpur 21 inches deep. As far as Ab-i-gum the permanent way is that previously used on the old Bolan Railway, being partly double-headed steel rails, 75 lbs. per yard, on Denham-Olpherts cast-iron sleepers, Figs. 4, Plate 7; and flat-footed steel rails, 75 lbs. per yard, on steel transverse trough sleepers, of the ordinary State Railway pattern. Although the Denham-Olpherts seems a fragile style of cast-iron sleeper, or plate, it stood well among the shingle and boulders in the Bolan, until battered by the stones during floods. From Ab-i-gum to the summit at Kolpur, flat-footed steel rails are used, weighing 100 lbs. per yard, on steel transverse trough sleepers with corrugated or buttressed lugs, Figs. 3 and 5. The sleepers are 8 feet 9 inches long, and weigh 135 lbs. each; and each is fitted with a steel key and with a distance-piece, weighing together 3 lbs., Figs. 6, Plate 7. The steel transverse trough sleeper seems admirably suited for these frontier railways, so long as it is not laid in the moist soils heavily impregnated with salts, where nothing seems to last except cast-iron and wood. With the steel trough sleeper and the Denham-Olpherts systems, "creep" is unknown on the Sind-Pishin and Bolan Railways. For the "catch-sidings" the old iron and other obsolete rails from the old Bolan Railway will be used.

The locomotives for working the material trains on the lower lengths were the ordinary L class, with six wheels coupled, weighing 46 tons exclusive of tender; but for the steep gradients four of the special locomotives supplied, in 1888, to the Khojak Tunnel works were used.¹ These are specially-designed eight-wheel coupled tank-engines (with the tank over the boiler), the coupling-rods being joined together with ball-and-socket joints to increase their flexibility on curves. The capacity of the tanks

¹ Minutes of Proceedings Inst. C.E., vol. cxii. p. 311.

and coal-bunkers was afterwards increased, so that each engine now weighs over 63 tons, and the ordinary loads were 100 tons on the 1 in 25 (4 per cent.) gradients. The fuel was a mixture of local and English coal, except on the steep gradients, where only English coal was used. Special engines are being made for this railway, each of which is to take 170 tons, in addition to its own weight, at 8 miles an hour up the 1 in 25 (4 per cent.) gradients; and 250 tons at 10 miles an hour up the 1 in 33 (3 per cent.) gradients.

The lowlands of this district are literally the hottest part of the earth's surface, the thermometer often registering 124° F. in the shade. In the winter the upper passes are filled with snow, and the temperature falls to 18° below zero, rendering out-door labour impossible. The new railway rises 5,440 feet in a length of about 55 miles; or 660 feet lower than the Sind-Pishin Railway (Harnai route) on an undulating length of about 100 miles. Both summits are, however, higher than those on European mountain railways, the Semmering being 2,500 feet, the St. Gothard 3,800 feet, the Mont Cenis 4,200 feet, and the Brenner 4,400 feet above sea-level; while the Mushkaf-Bolan height is 5,874 feet and the Sind-Pishin height is 6,534 feet.

Owing to the low fluctuating values of the rupee during recent years, and to special circumstances pertaining to this railway, no proper comparison can be made between its cost and that of mountain railways in other countries. It may be stated, however, that the estimated cost of the earthworks, including rock cuttings, is Rs.31,73,579, or Rs.54,018 per mile; tunnels, Rs.34,66,604, being at the rate of Rs.357 per lineal foot; large bridges (of 40-foot spans and over), including girders, complete, Rs.59,45,543, or Rs.1,01,200 per mile; small bridges (of 20-foot spans and under), including girders, complete, Rs.23,53,906, or Rs.40,066 per mile; the total of the estimates sanctioned for the new works, 58·75 miles long, being Rs.2,00,85,470, or at the rate of Rs.3,38,088 per mile, complete.

Under the rules of the Indian Public Works Department, the Author retired in July, 1894; and, since then, this railway has been completed by his successor, Mr. C. W. Hodson, M. Inst. C.E., with a saving on the original estimates. Unfortunately, the financial straits of the Government of India did not allow of sufficient funds being annually provided for so active a prosecution of the works as was expected when they were sanctioned, which added considerably to their cost, gave them a bad reputation in the eyes of people seeking work, and delayed their completion by

eighteen months. The work was all done under the "petty contract" system. The petty contractors were natives of India and Afghanistan, many of the latter being unable to either read or write. The unskilled labourers were from Afghanistan, Hazara and the Punjab. Pathans make excellent "navvies," using their picks, shovels, drills and wheelbarrows "as if to the manner born," and find this kind of work more profitable than picking up a precarious existence by raiding and robbery. All skilled labour, such as that of masons, carpenters and other artisans, was imported from the Punjab and Kurrachee at high rates of pay, as the Bolan has a bad name for sickness and expensive living. Besides the crowds of different animals carrying bricks, stones, cement, &c., to the masonry works, great numbers of donkeys, mules, camels and other pack-cattle were employed carrying earth to the high embankments, their passage from and to the borrow-pits having the effect of consolidating—punning in fact—the loose soil. There were also many miles of tramways in use, of 18-inch, 24-inch, 30-inch, and metre-gauges. From the temporary foundry, which was erected at Hirok shortly after these works were started, the output was between 5 tons and 7 tons a month; consisting of tramway wagon-wheels, bearings, brake-blocks, barrow-wheels and numerous other articles; the scrap mostly used being the broken Denham-Olpherts sleepers with which the Bolan torrent was strewn. The cost of working this foundry was amply repaid, as, besides saving the heavy railway freight from Kurrachee, everything was made more cheaply and of superior workmanship. Dispensaries and hospitals, with the necessary medical staff, were established in the neighbourhoods of the heaviest work on the different districts; and such very stringent sanitation was enforced throughout that there was no epidemic of sickness.

In selecting the alignment, care was taken to avoid running unnecessarily into engineering difficulties, but such difficulties as were unavoidable were boldly met; and, the Author believes, this new railway will give a safe and stable line of communication between the plains and the Baluchistan Plateau, after such unforeseen minor weak points have been rectified as are sure to develop on the heavy works of this mountain railway, through so wild and difficult a country. Successful maintenance of such railways can only be ensured by attending to the first signs of danger, and by skilful promptness in initiating repairs; while the policy of niggardly vacillation, or economical weakness, and strict adherence to routine, induces expensive and, not infrequently, ruinous disasters.

The old Bolan Railway, *via* the Kundilani Gorge, has now

entirely disappeared, and the materials been used on the new railway. It has been stated that the narrow Dozan Gorge is probably unique, in that traces of two abandoned railways and a wrecked military road can still be seen in it. A train was run through from Sibi to Quetta, over the new railway,¹ in five hours, the distance being $87\frac{3}{4}$ miles; and the Government have ordered the "bunched" steep-gradients, from Ab-i-gum to Kolpur station (the summit), to be laid with a double line.

The following Table shows the distances of various points on the line from Kurrachee, the seaport:—

	Distance from Kurrachee.	Remarks.
Ruk Junction	Miles. 318	
Sibi	451 $\frac{1}{2}$	
Mach	498	
Kolpur	513	
Quetta	539 $\frac{1}{2}$	Mushkaf-Bolan summit.
Bostan Junction	559	Mushkaf-Bolan route.
Khojak " Tunnel	585 $\frac{1}{2}$	Harnai
Chaman	605	6,398 feet above sea-level.
	627	(Nearest military post to Kandahar, 4,505 feet above sea-level.)

Between Chaman and Kandahar, a distance of some 75 miles, the country being easy and undulating, the rails can be very quickly laid when required.

The district engineers were Mr. W. A. Johns, Assoc. M. Inst. C.E., in the Mushkaf Valley; Mr. C. J. Cole, Assoc. M. Inst. C.E., at the Panir Tunnel and the Lower Bolan; and Mr. T. E. Curry, M. Inst. C.E., in the Upper Bolan. The engineers on these frontier railways, in addition to their engineer duties, have to perform those of contractors' agents, and commissariat officers, as all food supplies, &c., for the work-people have to be imported from distant markets, no supplies of any kind being obtainable in the districts traversed.

The Paper is accompanied by two tracings from which Figs. 1 to 6, Plate 7, have been prepared.

¹ *The Times*, 1 October, 1895.

APPENDIX.

PARTICULARS AND COSTS OF THE TUNNELS.

Name of Tunnel.	Length.			Cost.		Time Taken.		Nature of Materials Tunnelled through.
	Half Lined.	Three quarters Lined.	Total.	Total, including Tools and Plant.	Per Foot Run.	Driving Heading.	Total.	
Mushkaf (No. 1)	Feet.	Feet.	Feet.	Rupees.	Rs.	Days.	Months.	
" (No. 2)	..	470	470	1,25,012	266	73	19	
" (No. 3)	..	650	650	1,70,662	263	93	20	
Cocked Hat (No. 4)	..	366	366	89,793	245	59	20	
Tunnel (No. 5)	..	527	527	1,34,862	256	83	20	
Bella Vista (No. 6)	..	353	353	86,298	244	41	19	
Tunnel (No. 7)	477	262	739	2,27,037	307	92	15	Conglomerate and clay bands.
" (No. 8)	..	306	306	76,104	249	54	19	Red clay and con- glomerate.
Panir (No. 9)	520	2,698	3,218	13,67,727	425	274	34	South half, clay and soft sand- stone. North half, limestone.
Tunnel (No. 10)	..	319	319	93,776	294	91	21	Limestone.
Rod Clay (No. 11)	..	417	417	1,26,787	304	61	29	Shattered lime- stone and red clay.
Rift (No. 11a)	..	540	540	1,33,889	248	(Cut and cover)	11	Clay and lime- stone boulders.
Monte Carlo (No. 11b)	155	15	170	51,468	302		19	Limestone.
Seetal (No. 12)	..	1,035	1,035	2,96,551	286	281	30	Limestone con- glomerate and earthy bands.
Sir-i-Bolan (No. 13)	..	335	335	88,374	264	50	12	Earth, shingle and limestone con- glomerate.
Pir Panjeh (No. 13a)	..	200	200	41,351	207	(Cut and cover)	4	Shattered lime- stone, earth and boulders.
Cascade (No. 14)	189	353	542	1,66,880	308		15	Hard blue lime- stone, with soft yellow arena- ceous limestone at north end.
Windy Corner (No. 15)	..	406	406	1,28,690	317	79	24	Brecciated lime- stone, much contorted and dangerously shat- tered, required careful timbering.
Mary Jane (No. 16)	..	581	581	1,45,363	250	92	24	Laminated lime- stone, much contorted and shattered.
Summit (No. 16a)	..	315	315	58,769	187	(Cut and cover)	9	Shattered lime- stone with clay and boulders.
				11,700	36,64,793			

The average cost per-lineal foot is Rs.313 complete.

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(*Paper No. 3005.*)

“The Tunnels on the First Division of
the Mushkaf-Bolan Railway, India.”

By WILLIAM ARTHUR JOHNS, Assoc. M. Inst. C.E.

ONE of the most formidable obstacles to railway communication between the valley of the Indus and the highlands of Baluchistan, leading to Afghanistan, is the narrow but lofty mountain belt that, rising suddenly from the plains, forms the western boundary of Sind and the Punjab. This belt becomes reduced to about $1\frac{1}{2}$ mile in width where the Mushkaf river debouches upon the plain, and the ridges diminish in height and number, till only some half-dozen parallel and comparatively low hills have to be passed. Just before emerging from these hills at this point, the river, after running parallel to the range from east to west, suddenly turns to the south and then again to the east, thus forming a U bend, the length of each leg being about $\frac{1}{2}$ mile and the width between a little more. The Mushkaf-Bolan Railway traverses the range at its narrowest point near the middle of, and at right-angles to, the U bend. This entails two crossings of the Mushkaf river each about 550 feet long, and six short tunnels aggregating $\frac{1}{2}$ mile in length, Fig. 7, Plate 7. This piece of the railway, 6,000 feet long, has cost about Rs.12,00,000, exclusive of permanent way.

BRIDGES.

The piers and abutments of the bridges are built with a facing of brickwork laid in Portland-cement mortar (1 of cement to 4 sand), and a hearting of cement concrete; while the girders are of 150 feet clear span, of the heavy Mushkaf-Bolan type with ballasted roadway. The brick face-work of the piers is 2 feet 1 inch and 2 feet 6 inches thick in alternate double courses, with through bonding courses 1 foot thick every 4 feet in height. The upper 5 feet to 10 feet of the piers and abutments are of solid brickwork throughout; while in the lowest 12 feet of the concrete hearting large vitrified brick-blocks were set in the concrete. This

is an admirable and economical style of work in retaining walls, but is not so desirable in piers, unless an exceedingly rich mortar is used. If the Author could be sure of having no second-class bricks in the face-work, he should prefer using second-class bricks for the hearting, instead of concrete. Neither is absolutely satisfactory, but first-class bricks were not obtainable in sufficient quantity for the piers throughout, owing to the demand of them for tunnel arching, and the scarcity of fuel for burning them.

TUNNELS.

The tunnels were situated within a short distance of each other and were easily supervised; they were driven through similar strata and built under the direction of English miners at low contract rates for labour (not materials). The strata traversed were thick bands of indurated red clay or marl, alternating with thin beds of soft sandstone. The clay air-slaked rapidly on exposure, and, owing to irregularities in stratification, was very treacherous to excavate without considerable timbering.

Six English miners and a foreman were therefore employed for the timbering, and to supervise the work generally. They worked in pairs, each pair having charge of two tunnels. They were paid Rs.300 per month, plus allowances for overtime or piece-work which averaged about the same amount. Though their emoluments were high they were invaluable, for the ground was excavated to the correct size, while labour, timber, and explosives were employed to the best advantage, so that the tunnels in which these miners were employed compared favourably in economy with others, on this railway, which were carried out entirely by native labour. These English miners were only required for heading driving and the excavation of the arch; the excavation for the under-pinning was accomplished entirely by native labour. In dealing with English miners, it was found that payment of overtime should be avoided as far as possible, and a system of payment by piece-work adopted, or a bonus given on progress. During the progress of the headings until the ground was opened out, overtime was paid them, with a small bonus per lineal foot; but, as soon as the excavation of the arch was begun and the nature of the strata seen, all overtime was stopped, and a sum of Rs.40 was paid to each miner for each length of 15 feet excavated. Thus, if two miners excavated an aggregate of eight lengths during the month in both their tunnels, each received

Rs.320 in addition to his pay. The total cost of these miners, including pay on board ship and passage-money, amounted to about 10 per cent. of the cost of the tunnels, or Rs.24 per lineal foot of tunnel. In a cooler and healthier climate than that of the Mushkaf Valley, and on longer tunnels, this cost could be considerably reduced. The tunnels are all semi-circular, Fig. 8, Plate 7, and built for a double line, with battering side-walls 7 feet 6 inches high, the width at springing being 29 feet 6 inches, and the height from the formation level to the intrados 22 feet 3 inches.

At the end of the hot weather of 1893 work was begun on the approach cuttings of all six tunnels; but, as the miners arrived from England before these were ready, top headings were also started, and pushed on simultaneously with the approach cuttings. In order to save the time of these men, the headings were commenced without any previous squaring or cutting back of the hill-side, and were afterwards, where necessary, blown down and converted into open cuttings. The tunnels were too short to make it worth while to drive bottom headings, so as to start "break-ups" inside and thus obtain extra working-faces; while a top heading gives better ventilation than a bottom one, an important consideration in weather when the thermometer stands at 120° in the shade. The Author would, however, always drive a bottom heading in a tunnel more than 600 feet long, if English miners were obtainable. The size of the headings was 7 feet by 7 feet, and the crown was kept about 5 feet above the intrados of the arch to allow for the brickwork and timbering. The headings were driven by petty contract, explosives being supplied free by Government, and the miners doing the timbering with the help of the petty contractors' coolies, chiefly Peshawari Pathans. The average progress was 5 feet per day, and the rate paid the petty contractor was Rs.5 per lineal foot. The explosives (chiefly dynamite) were issued by the miners, and cost about Rs.9 per lineal foot of the 50 cubic feet section. Powder was not found to give such good results as dynamite. All holes were bored by hand, no drilling machinery being used.

As the longest tunnel was just over 600 feet in length no artificial ventilation was necessary, but progress was slightly slower in consequence. The "settings," where used, were deodar logs 9 inches in diameter supported on sleeper side-trees and spaced 3 feet or 4 feet apart. The poling-boards were of jungle-wood 12 inches by 1½ inches, and the cost of the timbering averaged about Rs.2 per lineal foot. The headings were begun

in October and November 1893, and were completed in December and early January; but, owing to the approach cuttings being lengthened to shorten the tunnels, the arching could not be started till February and March 1894. The cost of the headings, labour, explosives, timber and miners was Rs.18 per lineal foot, or about Rs.360 per 1,000 cubic feet. The method of working is shown in Fig. 9, where 1 indicates the top heading, 2 the excavation of the arch and gullet, and 3 the sides and underpinning. The last operation is best done in two parts, as shown by dotted lines 3a and 3b, if the ground is good.

The excavation for the arch was begun by building a short length of masonry—about 6 feet—of the standard section, close up to the face of the tunnel, on which to rest one end of the bars. The ordinary English system¹ of timbering was adopted, but the excavation was only taken down to springing level. As there was no bottom heading a sill was not required to carry the props supporting the leading ends of the bars, a thick plank or a half baulk of timber was used instead, to give a level surface for the props to rest on. The excavation was taken out in 15-foot lengths. The number of bars worked was generally ten, four being "drawing-bars" and the rest "taking-out" bars. The drawing-bars were between 13 inches and 15 inches in diameter and 21 feet 6 inches long; the taking-out bars were between 10 inches and 13 inches in diameter and 17 feet 6 inches long; and the props were 9 inches in diameter, all of Malabar teak costing Rs.1 annas 5 per cubic foot at Kurrachee. The poling-boards were 12 inches by 1½ inch jungle-wood planks, costing 1½ anna per lineal foot. The work was carried out by petty contract, the rate being Rs.80 per 1,000 cubic feet, including explosives. The cost of the latter varied between Rs.25 and Rs.35 per 1,000 cubic feet, equal to about Rs.18 per lineal foot, according to the nature of the ground. English powder costing Rs.38 per 100 lbs. was chiefly used, but country powder sometimes gave good results after a length was well opened out, while dynamite was useful in the corners. The total cost of English powder alone, on the arch section of 450 cubic feet, was about Rs.8 per lineal foot of arch excavation. The petty contractor was also paid Rs.10 for each bar worked in the length, the timbering being erected by his coolies supervised by the miner. About twenty-five men were employed on the face including runners-out; work was carried on night and day, and the time taken to excavate a length varied

¹ "Practical Tunnelling," by F. W. Simms, London, 1895.

between seven and ten days according to circumstances. During the hot months, June to September, 10 per cent. extra was paid for both excavation and timbering. During the excavation of the arch, a gullet 10 feet wide was driven at formation-level up the centre of the tunnel, and, as soon as the excavation of a length was complete, the ribs were set and the masonry of the arch begun.

The centres for the masonry of the arch were of the usual skeleton type, made of three plies of 12-inch by 3-inch deal or kucha teak planking, the central sweep breaking joint with the two outside joints, all of which were covered with wrought-iron plates on each side, 24 inches by 8 inches by $\frac{1}{4}$ inch thick, bolted through with six bolts $\frac{3}{4}$ inch in diameter. These ribs were generally spaced 5 feet apart, but sometimes they were 7 feet 6 inches. The laggings were deal or kucha teak of 6-inch by 3-inch scantling, and 15 feet long. As a rule the excavation was taken down 6 inches below springing, and side-walls 1 foot 9 inches high were built to template before the ribs were set. The Author considers this is a good practice but not essential; where carried out the ribs required to have 15 inches cut off their heels. The masonry was of brickwork throughout and usually five rings thick, set in Portland-cement mortar, composed of 1 part of cement to 3 parts of sand. All spaces between the extrados and the excavation were filled with brickbats, set in cement mortar to a height of 4 feet above the springing; above that was laid dry. Any packing at the "leading end," or directly behind the ribs, was set in mortar as an extra precaution. The bricks were all first class and overburnt, hardness being the primary consideration and shape of little importance. The arch was turned by petty contract, and generally by the petty contractor for the excavation. The rate was Rs.14 per 100 cubic feet, Government supplying bricks and cement free. Sand cost the petty contractor between Rs.1 and Rs.2, and labour between Rs.9 and Rs.10, per 100 cubic feet. Water was led to the works in pipes from a point about 9 miles up the river, there being none in the lower gorge. The force employed by the petty contractor was six bricklayers and about twenty-five coolies; and the turning of a length, including the setting of the ribs and the key, on which only one man could work, occupied four shifts. No night-work was permitted, and each length of arch was allowed thirty-six hours to set before the excavation of the next length was started.

Three to four lengths a month was an average rate of progress at each tunnel; but this could easily have been increased by two lengths monthly, by working night and day on the masonry, and

then starting the excavation as soon as the arch was keyed in. The total cost of the masonry, including materials, was :—

	Rupees.
Cement	21
Bricks, including carriage by rail	25
Labour and sand	14
Centres and laggings (varies inversely as length of tunnel)	10
Sundries, such as lighting, supervision, brickbats and packings} not included in measurement, rib-setting, &c.	11
Total per 100 cubic feet	81

The petty contractors were paid only for sectional measurements, and the actual measurements were at least 7 per cent. in excess ; the rate of actual work executed being about Rs.75 per 100 cubic feet.

It is when the under-pinning is begun that the advantage of the gullet carrying the tram-lines at formation level becomes apparent. The same lines that carry the spoil from the arch excavation suffice for the under-pinning also, and there is none of the trouble and delay attendant on having two lines on different levels. The excavation for the under-pinning in the shorter tunnels was not started till the arching was complete ; in the longer tunnels it was begun as soon as the arching was about 200 feet from the entrance. As a rule one side was excavated at a time, "break-ins" being made every 45 feet or less. The excavation below the arch was taken out in 6-foot lengths ; and, as soon as 12 feet of masonry had been built at any one "break-in," work proceeded at both faces. The quickest way was to first take down the side of the excavation, leaving only a 3-foot benching underneath the arch masonry, and then to excavate below the arch in short lengths ; but when the ground was treacherous the excavation both below and inside the arch was taken out at one operation. Miners were not employed, and the petty contract rate paid was Rs.60 per 1,000 cubic feet, including explosives. This rate was not very profitable to the petty contractor unless he had the contract for the brick-work as well. Native powder costing Rs.16 per 100 lbs. was used to a considerable extent ; but English powder and sometimes dynamite were needed in the corners of the foundation. The explosives may be taken as costing between Rs.20 and Rs.25 per 1,000 cubic feet. No timbering was required, the ground being dry and hard. The brickwork in the side-walling is similar in thickness and style to that in the arching, but the mortar contained 1 part of cement to 4 of sand. The cost of this masonry amounted to Rs.60 per 100 cubic feet, thus :—

	Rupees.
Cement	16
Bricks	25
Labour and sand	14
Lighting, supervision, &c.	5
Total	60

The rate for labour was admittedly high, but it was a rule that each length of brickwork should be completed on the day it was begun, which was too much for one mason though not enough for two. The side-walls were built with a batter of 1 in $7\frac{1}{2}$, which is preferable to building them vertical. Their foundations were levelled up with between 4 inches and 6 inches of concrete. It should be stated here that, in turning the arch, since the bottom courses become dirty on the lower side, these were always temporarily laid dry, being afterwards removed and the side-walls pinned up to the second course of the arch. This is cheaper than laying the arch on either concrete or timber, as is sometimes done. Underpinning can be carried on at any speed depending upon the length of the tunnel, but, in the longest of these tunnels, 600 feet was completed in a month.

The plant was of the simplest description. For "heading driving" light $\frac{1}{2}$ -inch drills were used, about 5 feet 6 inches long. In the "lengths" and under-pinning $\frac{1}{2}$ -inch, 1-inch, and $1\frac{1}{2}$ -inch drills were used, according to the position of the holes. In the headings 1-foot 6-inch gauge tram-lines, and 10-cubic-foot wagons were used; but the spoil from the arch and under-pinning was led out in 45-cubic-foot "fiddle-stick" metre-gauge wagons, running on wheels 1 foot 6 inches in diameter. The dimensions of the tip-wagons were 7 feet 6 inches by 3 feet by 2 feet. Old iron flat-footed rails, weighing 60 lbs. per yard, were used, lighter rails not being obtainable.

A list of the lengths of the tunnels and their total cost is appended, the cost of the temporary line and of the water-supply being omitted.

LENGTHS OF THE COMPLETED TUNNELS.

	Feet.
No. 1. Mushkaf	470
No. 2. Mushkaf	650
No. 3.	866
No. 4. Cocked Hat	527
No. 5.	353
No. 6. Bella Vista	211
Total length	<u>2,577</u>

STATEMENT OF COST.

	Rupees.
Excavation, 1,829,915 cubic feet	2,79,977
Concrete, 11,845 cubic feet	5,008
Masonry, 437,493 cubic feet	3,29,913
Twelve portals	24,000
Tools and plant (chiefly wagons and sleepers, as the rails were all sold)	9,872
Sundries	3,896
Total	<u>6,52,066</u>

being at the rate of Rs.253 per lineal foot of complete tunnel. The rate for excavation per thousand cubic feet is Rs.153, made up as follows:—

	Rupees.
Labour and explosives	102
English miners' wages	33
Timber	8
Sundries	10
Total	<u>153</u>

The following explosives were used in these six tunnels:—

	Rupees.
English powder, 53,575 lbs.	20,857
Country powder, 44,284 lbs.	7,080
Dynamite, 17,950 lbs.	26,865
Detonators, 52,974	2,119
Fuse, 581,300 feet	6,757
Total	<u>63,178</u>

being at the rate of Rs.24½ per foot run of complete tunnel; or Rs.34½ per thousand cubic feet of excavation.

The approach cuttings were begun about the 28th September, 1893, and the last tunnel was completed early in June 1895, without any attempt having been made to push the work, and in spite of a great deal of sickness among the English miners, who, however, kept the work in progress through the hot weather of 1894—an unprecedented performance in that terrible climate.

The Paper is accompanied by two tracings, from which Figs. 7 to 9, Plate 7, have been prepared.

(*Paper No. 2960.*)

“The Tunnels on the Second Division of
the Mushkaf-Bolan Railway, India.”

By CHARLES JOHN COLE, Assoc. M. Inst. C.E.

In this Paper is given an account of the tunnels on the district of the Mushkaf-Bolan Railway which was under the charge of the Author.

The direct route to Quetta, *via* the Mushkaf Valley, involves tunnelling through the divide into the Bolan Valley, which is 25 miles from Sibi, the terminus of the Indian Plains Railway system, and $451\frac{1}{2}$ miles from Karachi, the nearest seaport. It is pierced by the Panir Tunnel, 3,218 feet in length, the longest on the new railway, built for a double line of 5-foot 6-inch gauge with the lines at 14-foot centres. In Fig. 11, Plate 7, showing a longitudinal section of the tunnel, it will be observed that no shafts were practicable. Reverse gradients of 1 in 100 and 1 in 1,000 meet in the middle of the tunnel. A steeper gradient than 1 in 1,000 would have been more convenient for construction purposes, and would have facilitated the drainage of the approach cutting. Had water been met with in this portion of the tunnel the advantage of a steeper gradient would have been still greater. The tunnel is straight, running nearly due east and west; the eastern portal is in the Mushkaf Valley, and the western in the Bolan.

A 6-inch transit theodolite was used for fixing the permanent alignment which was marked by masonry pillars, particular care being taken with the trunnion adjustments, as some of the sights had to be taken at very steep angles. The horizontal error on the junction of the headings was 3 inches. Actual measurement of the length over the hill was impracticable, so triangulation had to be solely depended on; the error in length was inconsiderable. The total length of heading driven was 3,053 feet, the remaining 165 feet being in cut and cover. The western heading was begun on the 20th November, 1892, and the eastern on the 4th January, 1893. The headings met on the 21st August, 1893. The average daily progress over both was 13 lineal feet; the best

month's progress being 453 lineal feet. At about 1,360 feet from the eastern portal the strata tunnelled through change from alternating bands of sandstone and red clay to nummulitic limestone of varying degrees of hardness.

Rock-drills driven by compressed air were worked from the beginning in each heading. One air-compressing station, situated 600 yards from the Bolan or western side of the hill, served both headings. A branch from the Bolan temporary line was laid to deliver the plant at the entrance of the gorge 200 feet below the tunnel formation-level. This arrangement for the delivery of plant presented less difficulty than transport up the Mushkaf Valley to the eastern side of the hill. The piping for the transmission of air was 4½-inch wrought-iron tubing. The pipe-line carried over the hill, at a lower point than the centre-line, was 6,500 feet in length, with a rise of 800 feet, the joints throughout being screwed up with white lead to prevent leakage. The air-compressing plant consisted of two pairs of 20-HP. multitubular boilers, two pairs of single-cylinder tandem air-compressing engines (14-inch cylinders and 2-foot stroke), and two air-receivers of 270 cubic feet capacity each. These constituted two sets of plant, which were originally ordered for the Khojak Tunnel, from Messrs. Schram and Company, London, in 1886. The arrangement of one set of this plant is shown in Figs. 29, Plate 7. The average pressure maintained in the air-receivers at the station was between 70 lbs. and 60 lbs. per square inch. The loss in transmission, according to gauge readings, was 10 per cent., and 25 per cent., at the west and east portals respectively. The air pipe-line over the hill was exposed to the direct rays of the sun, or a maximum temperature of 170° F. throughout its length, and the heating of the air in transmission moderated the loss from friction due to the bends necessitated by the rough nature of the ground over which the piping was laid. Three boilers were used for driving the heading; the screenings of coal from local collieries being used for fuel. Each boiler was found to consume 1½ ton of screenings in twenty-four hours, or 7 lbs. per HP. per hour, and 6 gallons of water per HP. per hour. 4-inch Climax rock-drilling machines of 9-inch stroke, made by Messrs. R. Stephen and Son, Carnbrae, Cornwall, were used, and 3½-inch Schram drills of 6-inch stroke. In the limestone the Climax, although a heavy machine to move about and consuming more air, was found more serviceable than the Schram, while its simplicity also recommended it to the native workmen. The Schram drill was found more useful in the clay and sandstone strata. Two machines of each kind were generally worked on

one stretcher bar, 8 HP. being required to work one Climax machine. The following was the cost of the power over the whole length of heading per cubic yard of excavation:—

	Rupees.
Coal screenings, 0·26 ton	2·7
Engine-drivers and stokers (native) wages	0·66
Oil and stores	0·34
 Total	 3·70

The following Tables give details of the explosives used in the headings:—

TOP WEST HEADING.

	Quantity.	Rate.	Amount.
	Rs. a. p.	Rs. a. p.	
Dynamite and gelignite . . .	25,560 lbs.	1 8 10	39,671 4 0
Detonators treble . . .	14,900 No.	3 7 0 per 100	512 3 0
" quintuple . . .	5,655 "	4 3 0	226 8 2
" sextuple. . .	21,800 "	6 0 0	1,278 0 0
Fuse red coils . . .	2,553 cs.	0 9 6	1,515 13 6
" rubber coils . . .	392 "	0 11 3	275 2 0
" black coils. . .	350 "	0 3 0	65 10 0
Total cost . . .	..	..	43,544 3 8

Total excavation in Top West heading . . . 113,266 cubic feet.

Dynamite and gelignite per cubic yard 6.09 lbs.

Total cost of explosives per cubic yard. Rs. 10·3

Explosives per lineal foot **Rs. 25·7**

TOP EAST HEADING.

	Quantity.	Rate.	Amount.
	R. s. d.	s. d. p.	R. s. d. p.
Dynamite and gelignite . . .	10,765 lbs.	8 10	16,708 2 10
Detonators treble . . .	8,236 No.	3 7 0 per 100	283 1 9
" quintuple . . .	7,500 "	4 3 0	314 1 9
" sextuple . . .	1,000 "	6 0 0	60 0 0
Fuse red coils . . .	1,360 cs.	0 9 6	807 7 0
" rubber coils . . .	50 "	0 11 3	35 2 6
Total cost . . .	..	..	18,207 15 0

Total excavation in Top East heading . . . 105,219 cubic feet.

Dynamite and gelignite used per cubic yard 2·7 lbs.

Total cost of explosives per cubic yard. Rs. 4·6

Explosives per lineal foot Rs. 13·3

In the east heading, through soft material, between ten and

twelve holes were drilled in the face each round. The holes were $1\frac{1}{4}$ inch in diameter at the bottom, $2\frac{1}{2}$ inches at the top, the depths averaging about 3 feet, and the usual charge was about 40 lbs. of dynamite. In the west heading, through limestone varying between a spongy and a crystalline character, there were sixteen or twenty holes in the face, charged with 50 lbs. of dynamite. The drills varied in length between 2 feet and 6 feet, the chisel point being chiefly used.

The size of the west heading in hard ground was 8 feet by 8 feet; in the soft ground in the eastern portion the size was 10 feet by 8 feet. The west heading was begun on the 20th November, 1892, and the east on the 4th January, 1893; the two met on the 21st August, the average progress per day being 13 lineal feet over both headings. The maximum daily progress was 15 feet at the east, and 11.5 feet at the west heading; the average number of shifts per day was 2.4; the average time of drilling and blasting per shift was 4.2 hours in the east and 5.9 hours in the west heading, and the average length of hole bored per shift was 50 feet and 69 feet at the east and west headings respectively. The headings met 1,695 feet from the west face at the change in the strata from limestone to red clay and sandstone. Candles were used in lighting the heading, the consumption amounting to about 2 lbs. per lineal foot. For timbering, props of Malabar teak, costing Rs.2 per cubic foot at the site, jungle wood planking, $1\frac{1}{2}$ inch thick, and old deodar sleepers were used; the cost was Rs.10 per setting, or Rs.3 per lineal foot for settings up to 4 feet apart.

In the east heading, labour on the machines and mucking out cost Rs.4.5; on the west Rs.4.8 per cubic yard. The cost of the 3,053 lineal feet of heading is shown in the following Table:—

	Rupees.
Labour	37,673
Explosives, &c.	61,758
Compressed air	29,941
Timber	5,000
General charges	10,700
Total	<u>145,067</u>

Enlarging.—When the west top heading had advanced 500 feet, a bottom heading was begun, which was widened as it advanced to take two lines of metre gauge, Fig. 16, Plate 7.

The top heading was connected at intervals with the bottom heading by dump-holes, each of which thus gave two faces for

enlarging. In the bottom heading a short siding, Fig. 12, was cut under each dump-hole which kept the main line clear. The spoil from the top heading was tipped through the nearest dump-hole, so that the two lines in the bottom heading carried the whole of the material excavated. Fig. 13 shows the order in which the different enlarging operations were performed on the west side. The section was first taken out to a lunette 17 feet above formation level, and trenched on each side to 12 feet to take the arch. A line of metre gauge on the left-hand berm removed the spoil on one side, and the top heading line slewed to the right served to remove the remainder. The tunnel section, which is a very large one, was determined by the standard minimum dimensions for fixed structures outside stations on Indian State Railways, coupled with the proviso that the distance from the soffit of the arching to the formation level shall be a minimum of 22 feet 3 inches. The Government of India also ordered all tunnels to have a minimum of 100° of arching, as it is found that the hardest rock disintegrates under the action of the gases from the combustion of coal.

Fig. 19 shows the type of tunnel section on a straight line. Fig. 20 shows the flying-arch section adopted where the sides were sound enough to be left without side-walling; 550 lineal feet was so constructed, the remainder has side-walling for carrying the arch, as shown in Figs. 21 and 22. A length of 20 feet at each portal was built as shown in Fig. 23 to admit of defensive gates being erected. Refuges were provided at intervals, Fig. 21. The east and west portals are shown respectively in Figs. 27 and 28. Top and bottom headings, run simultaneously, were found to facilitate the work and preserve a good working organization. A fourth boiler was brought into use for the bottom heading and enlarging; but when the bottom heading was run up to meet the top heading in the middle of the tunnel, machine-work on the enlarging was stopped, as hand-labour was found to be cheaper. The following Table gives the cost, including explosives, and the quantity of dynamite expended in each portion :—

	Cost of Excavation per Cubic Yard.	Dynamite per Cubic Yard.
Portion 1, Fig. 18 (west heading)	Rupees.	Lbs.
" 2	22·0	6·0
" 3	22·0	6·0
" 4	4·86	1·2
" 5 }	5·3	1·0
" 6 }	2·5	0·5

The materials for arching the first 300 feet were brought in on the top side berm ; but when the excavation of the sides and underpinning advanced, a third line was laid in the bottom heading and almost entirely used as a masonry line, leaving two lines free for running out spoil. Materials for masonry, when the side berm was demolished, were run in at formation level and taken up ramps at the most convenient dump-holes.

Bricks for the arching from the soaking tanks outside, and Portland-cement and sand mixed dry in bags, were run in on metre-gauge trolleys. The mortar was prepared in wooden mixing-tubs, which could be moved about in the tunnel as required. The style of centering-rib adopted is shown in Fig. 17. The ribs were found to keep their shape well, and gave no trouble in re-sizing. There were forty-five in use when the work was at its height. The laggings were jungle wood planks 2 inches thick by 6 inches wide. In one portion of the tunnel six ribs were mounted on longitudinal framings carried on gantry wheels running on rails, and this 25 feet of centering was moved as the arching advanced. For the other lengths of arching the ribs were separate, and were wedged up in the usual manner above the springing of the arch segment. The arch segment was invariably founded on a concrete skewback consisting of 1 of Portland cement, 7 of sand, and 16 of broken stone. The skewback was broken away when the side walling was built, and for a height of 6 feet above it the arch segment was backed with concrete, consisting of 1 of cement, 5 of sand, and 12 of broken stone. The remainder of the backing was of rammed spoil, and immediately over the crown of the arch it was of stone in mud mortar. Special attention was given to the backing, so as to avoid all risk of shaking the arch masonry when blasting out the space for the side walling. The arch was built in rings, with three keys. The mortar consisted of 1 of Portland-cement to 4 of sand.

As will be seen from the longitudinal section of the tunnel, Fig. 10, Plate 7, the bottom heading was turned up to meet the top heading on a gradient of 1 in 30, at the junction of the hard and soft strata. It was unadvisable to have more ground open than absolutely necessary through the sandstone and clay strata in the eastern half of the tunnel, as the temporary line up the Mushkaf Valley had not reached the east portal, and, until this was laid, the saving of 20 miles in carriage of bricks by way of the Mushkaf Valley instead of by the longer temporary Bolan line, was a consideration. Owing to the shortness of the funds allotted to

the railway, delivery of girder-work was likely to delay the opening more than the tunnel work, so that rapidity of tunnel construction was not of such importance; and the extension of the temporary line in the Mushkaf Valley to the east face was consequently delayed.

The eastern portion with only one heading was enlarged as shown in Fig. 14. Underpinning 12 feet above formation level in the western portion gave trouble as the over-hang was too great, and twelve hours had to be given a portion of it to set before completion; so the depth of the underpinning in the eastern half of the tunnel was reduced to 10 feet. The top heading (1) was therefore lowered 4 feet, the light timbering being replaced by longer props. The portion (3) was then taken out and timbered for arching, the spoil being tipped through a traveller called a "shaitan," or devil, which advanced as portion (4) was excavated. The shaitan, Fig. 18, was not popular with the natives, and is more suited to European labour. The excavation of (5) was taken out as the arching advanced, and when the underpinning was completed the tunnel was ready for the passage of trains on the up line. A temporary line was for some time carried on (6) for the carriage of materials into the tunnel. The procedure already described was adopted in building and backing the arch. The tunnel was completed on the 31st August, 1895. The following Table gives the cost, including explosives, and the quantity of dynamite expended in each portion:—

	Cost of Excavation per Cubic Yard.	Dynamite per Cubic Yard.	Powder per Cubic Yard.
Portion 1, Fig. 14 (top heading)	16·3	2·71	..
" 2	2·7	0·1	0·05
" 3	3·2	0·08	0·08
" 4	1·4	..	0·13
" 5	2·0	0·1	0·08
" 6	2·0	0·1	0·08

Except for 400 lineal feet the side walling on both sides was carried in stone masonry up to the springing of the arch; above the springing the masonry was in brick. Fig. 15 shows the section of the underpinning. For the side walling, limestone from a quarry close to the western portal was used. It was well bedded and easily quarried, and presented no difficulty in giving a minimum 4½ inches

overlap in the joints. The courses were on an average 10 inches thick, so that the best possible work was procurable from the petty contractor. The cost of the side walling (including excavation of foundation and concrete) amounted to Rs.50; and of the arching in brick, Rs.99 per lineal foot, including concrete backing and rammed filling, giving a total cost of the tunnel masonry of Rs.149 per lineal foot.

First-class bricks at the kilns cost Rs.15 per 1,000; to this has to be added 45 miles of carriage by rail to the west portal, and 25 miles to the east; to the site of work at the west portal from the temporary Bolan line, a further charge of Rs.4 per 1,000 has to be added for carriage over a wire-rope incline rising 200 feet from the valley below. The presence of limestone grit in the soil rendered it impossible to manufacture bricks of any kind near the site of works.

To turn a 15-foot length of arching, five rings thick, down to 10 feet above formation level, six masons were employed, one between each centre rib, and fifty coolies; the time occupied being sixty hours. The best month's progress was 400 feet of arching. Wells unbreakable flare lights were used, supplemented with a few small oil-lamps. The mortar for the brickwork in the arch was composed of 1 of Portland-cement to 4 of sand; in the side-walling it was 1 of Portland-cement to 5 of sand. Sand for the masonry was an expensive item, as it had to be carried 8 miles by rail, and cost the contractor Rs.40 per 1,000 cubic feet at site of works. Fifteen thousand barrels of Portland-cement were used in the whole tunnel.

The temperature in the tunnel headings in the summer months ranged between 92° F. and 100° F., whilst outside a temperature of 104° F. at night and 120° F. in the shade during the day prevailed. There were numerous cases of sunstroke among the natives. Water exists in the Bolan in a few favoured places. The supply for the air-compressing plant and the masonry was brought down from springs 7 miles distant in a 4½-inch wrought-iron pipe-line. The pressure in the pipe-line at the foot of the hill, before ascending to the tunnel, was 160 lbs. per square inch. The pipe-line gave no trouble.

The wire-rope incline at the west portal started from a siding of the temporary Bolan Railway, which was on a gradient of 1 in 20, and was constructed on the three-rail principle. It was laid to metre gauge on a gradient of 1 in 2½, and small metre-gauge trucks, containing bricks, &c., after being run on to carriers with frames

made horizontal by wheels of different diameters, were hauled up by a 3-inch steel-wire rope working off a winding-engine.

The cost of English stores, such as explosives and Portland-cement, was heavy, owing to the low rate of exchange prevailing. The Portland-cement was supplied by the India Office Stores Department, and cost in Sibi (451½ miles from the nearest seaport) Rs.8·75 per cask of 4½ cubic feet, weighing 402 lbs. net. The cost included sewing up each cask in old sacking, and paying over the surface with hot pitch, which was done by contract at 1½ annas per cask. This "dammering" was found useful in protecting the cement from any ordinary shower of rain, and in holding the casks together in the rough handling they sustained, especially with camel transport.

The air-compressing plant, supplied to the Khojak Tunnel Works in 1887, was transferred at a valuation to the Mushkaf-Bolan Railway. The boilers and engines, since the completion of the Panir Tunnel, have been sold, and are now working elsewhere, not much the worse for wear.

The total cost of the explosives, stores, &c., used in the tunnel, is shown in the following Table :—

	Cost.	Rupees.
Dynamite and gelignite	126,000 lbs.	1,95,562
Powder	106,741 "	46,679
Detonators	287,550	10,582
Fuse	39,878 {coils of} 24 feet}	19,428
Candles	14,625 doz.	7,925
Kerosene oil	4,876 galla.	2,700
Timber . . . . .	..	23,620
12-inch by 1½-inch planking	131,000 lineal ft.	24,562
Small stores . . . . .	..	8.000
Total	<hr/>	<hr/>
	3,39,058	

or Rs.105·3 per lineal foot, of which explosives cost Rs.84·6 per lineal foot.

The statement does not include fuel and stores for the air-compressing plant, nor Portland-cement.

The labour rates were high, as the Bolan Pass has always been regarded by the natives as unhealthy, especially after the cholera epidemic of 1885. All labour was imported, Pathan unskilled labour travelled down during the winter months from Ghuzni and the adjoining districts. Skilled labour, Sikhs and Punjaubis, had a long railway journey across the Sind desert.

The following were the rates for labour :—

Timekeepers	1·5 rupee per day.
Mason mistris	2·0 „ „
Engine-drivers (natives) on air-compressing plant	1·25 „ „
Firemen (natives)	10 annas „
Natives working rock-drilling machines	1 rupee „
Natives drilling by hand on enlarging	10 to 12 annas per day.
Coolies, mucking out	9 „ „
Masons (native)	{ 1·25 to 1·5 rupee per day.
Carpenters and blacksmiths (natives)	0·75 to 1 rupee per day.
Coolies with masons	10 annas per day.

The total cost of the tunnel is shown in the following Table :—

	Cubic Feet.	Rupees.	Rupees.
Excavation, including heading	3,005,152	223	6,70,149
Concrete	90,000	38	36,000
Masonry, including portals	555,400	90	4,99,860
Debits for loss on stores and plant . . . . .	..	..	1,61,716
Total. . . . .	..	..	18,67,725

MINOR TUNNELS.

The following tunnels are situated high on the west side of the Panir divide, in the Bolan Valley. They were all constructed by native labour for a double line. The transport of materials to the site of works was difficult and expensive. Water was conveyed to each by wrought-iron pipes from the 4½-inch main already mentioned.

Tunnel No. 10 is 319 feet in length, and is cut through a limestone spur jutting out from the main hill, 400 feet from the west portal of the Panir Tunnel. The strata were found to be much shattered due to bending. A top heading 10 feet by 8 feet was driven through by petty contract. Light timbering, where necessary, was carried out with Government labour and material. The quantity of explosives used in the heading was 2,950 lbs. of dynamite, or 9·2 lbs. per lineal foot, 6,800 detonators, and 1,500 coils of fuse, the total cost amounting to Rs.16·9 per lineal foot. The section of the tunnel is shown in Fig. 21. The arch was of brick, and the side walling of stone, built as in the Panir Tunnel. The rate for enlarging was Rs.110 per 1,000 cubic feet, including explosives, and the masonry rates were the same

as those given for the Panir Tunnel. The total cost of the tunnel was :—

	Rupees.
Excavation, including heading	32,412
Concrete	1,806
Masonry, including portals	54,958
Debit for loss of stores, &c.	4,600
Total	98,776

Red Rock Tunnel No. 11. This tunnel, 417 feet in length, is on a curve of 1011·5 feet radius through a spur composed of broken limestone permeated with red clay. A top heading was run, and was timbered throughout by Government labour. The contractor for driving the heading was paid Rs.110 per 1,000 cubic feet, or Rs.2·9 per cubic yard, including explosives. The arch section adopted is that shown in Fig. 25, Plate 7, which is larger than that for a tunnel on the straight, to allow for the canting of vehicles on the curve. The brick arching was built down to 10 feet above formation level, in the manner described for the Panir Tunnel. The side walling was constructed in stone masonry. The contractor was paid Rs.80 per 1,000 cubic feet, including explosives, for enlarging. The rates for masonry were much the same as given in the Panir Tunnel, as the bricks had to be carried 1 mile up the steep hill-side on donkeys. The total cost of the tunnel is shown in the following Table :—

	Rupees.
Excavation, including heading and timbering	43,261
Concrete	5,120
Masonry	65,510
Debits for loss in stores, &c.	12,896
Total	1,26,787

The Rift Tunnel, No. 11 a. This is a cut and cover, 540 feet in length. All the cuttings on the railway, excepting the tunnel entrance cuttings and where material was required to make up the banks, were taken out for a single line, and this cutting, owing to its position, was taken out to the standard single-line width of 24 feet at formation level, that is, 19 feet on the left-hand side of the centre line and 5 feet on the right. The average depth was 50 feet through a saddle connecting an outlying spur with the main range. The greater part of the cutting had been taken down to formation level before the dangerous nature of the materials in the saddle became evident. They were

found to consist of red clay with large angular boulders overlying the limestone strata of the main range, which dipped below formation level towards the cutting at an angle of 25°. In addition there was found to be a layer of greasy yellow clay sandwiched between the material of the cutting and the limestone, which formed a greasy surface for the prismoidal mass of ground bounding the cutting on the hillside of the line to slide upon.

The cheapest and soundest treatment was a cut and cover, which was ordered by the Government of India, to be built for a double line as are the other tunnels and bridges. There was space for the side walling on the left side, but the double-line arching and right side walling presented some difficulties. Instead of widening or benching the cutting down, in order to build the arch and right side walling, it was determined to cut a gallery into the side of the cutting for this purpose, as shown in Fig. 26. This method proved very successful, and the greater part of the arching was built while material trains were running, it being of the greatest importance to carry the line through before the wet season, and so permit of the final dismantling of the temporary line in the torrent bed of the Bolan. The ribs were built for an arch segment 4 feet 6 inches above the springing. On the left side of the tunnel the lower 3 feet of arching was built to template on the side walling, and the centering ribs were set on this. On the right side the arch was founded in the gallery 4 feet 6 inches above the springing, or 12 feet above formation level, which 12 feet of walling was afterwards built in short lengths. The arching in the gallery was backed with concrete to a height of 3 feet 6 inches above the side walling on the left. Struts above the arching served to steady the right side of the cutting when blasting out the ground for the gallery. The right side showed a tendency to crack, as portions of the gallery were joined up; but this was counteracted by the concrete backing at the haunches of the arch, and by the rammed earth backing which was laid down as soon as each length of arching was completed. It must be admitted that the execution of this job was greatly favoured by the climatic conditions obtaining in the district, where the fine and wet weather occur with great regularity. The services of an experienced English miner were also of great value. The petty contractor was paid Rs.45 per 1,000 cubic feet, including explosives, for the open cutting. Eighty-four lbs. of English powder, 4 lbs. of native powder, and four coils of fuse, costing Rs.6, were used per 1,000 cubic feet. The rate for the excavation for the gallery and for the side walling was Rs.70 per 1,000 cubic feet, including

explosives. The brick masonry in the arching, and the stone masonry in the side walling, cost the same as in the Panir Tunnel. The tunnel, including the portals, cost Rs.133,889.

Monte Carlo Tunnel, No. 11b. This tunnel is 170 feet in length, and is on a curve of 1,011·5 feet radius. The spur tunneled through proved to be of limestone of a quality much more reliable than any of the others. The arch segment was of 34 feet span, as the sides were sound enough to carry the arching without side walling, Fig. 24; 60 feet of the arching was executed in concrete, composed of 1 cement, 2 sand, and 6 of small shingle. The contractor was paid Rs.300 per 1,000 cubic feet for the heading, and Rs.160 per 1,000 cubic feet for the enlarging, both rates including explosives. The tunnel cost Rs.302 per lineal foot.

Seetal Tunnel, No. 12, penetrates a high ridge of hard conglomerate parallel to the Bolan, and is 1,035 feet in length. The contractor was paid Rs.210 per 1,000 cubic feet, including explosives, for the top heading, 8 feet by 8 feet, the expenditure in dynamite being 95 lbs. per 1,000 cubic feet. The rate for enlarging was Rs.100 per 1,000 cubic feet, including explosives. The tunnel section adopted was that shown in Fig. 21.

The explosives and stores expended on the tunnel were 9,000 lbs. of dynamite, 31,000 lbs. of powder, 35,600 detonators, 87,900 coils of fuse, costing Rs.67 per lineal foot.

The cost of the completed tunnel was as follows:—

	Rupees.
Excavation, including heading	98,551
Concrete	8,000
Masonry, including portals	1,70,000
Debits for loss in stores	20,000
Total	2,96,551

The Paper is accompanied by three tracings and three photographs, from which Figs. 10 to 29, Plate 7, have been prepared.

(*Paper No. 2989.*)

“On the Construction of a Lock and Weir in the River Darenth, at Dartford.”

By WILLIAM HENRY THOMAS, M. Inst. C.E.

THE River Darenth rises at Riverhead near Sevenoaks, and traverses the valley to which it gives its name, passing through the villages of Otford, Shoreham, Eynesford, Farningham, Sutton at Hone, Darenth, &c., until it reaches Dartford, whence it flows, through embanked marsh lands, to its junction with the River Thames at Crayford Ness. Its bed, for the greater portion of its length, lies in the chalk formation. It is fed by springs, yielding at all seasons a considerable volume of water, and the river supplies water-power to several mills on its banks. The total fall between Riverhead and Dartford, a distance of 13 miles, is 285 feet.

The head of the navigation is Dartford, where the upland waters are retained by a weir, to which point ordinary tides flow. Between Dartford and the River Thames, a distance of $2\frac{1}{2}$ miles, a considerable amount of traffic has been carried on for many years; and the navigation is controlled and regulated by the Dartford and Crayford Navigation Commissioners, who also have jurisdiction over the River Cray between its junction with the Darenth, about 1 mile below Dartford, and Crayford. The amount of the traffic may be appreciated from the revenue which in 1893 reached £700, the tolls being 1*d.* per ton on all classes of merchandise or goods in or out. By the Dartford and Crayford Navigation Act, the Commissioners have power to levy tolls, of a maximum of 3*d.* per ton, and are bound to keep the Rivers Darenth and Cray free for navigation by the removal of banks, shoals, &c. They are also required to expend on the improvement of the navigation any profits which may accrue. Prior to 1894, when the works described in this Paper were commenced, the navigation on the river, and more particularly the handling of the traffic when it arrived at Dartford, was restricted to a few hours on each tide; the bed of the river at that time being 3 feet above Ordnance datum, and the channel, but for the land-water flowing down, being dry for about

seven hours out of twelve. The chief inconvenience arising from this circumstance was that if a barge arrived at Dartford on the top of the tide and berthed alongside any of the wharfs, it was soon left high and dry; and if, as was frequently the case, there were goods to be delivered at other wharves, an entire tide would be lost at each. The same difficulty had to be encountered in loading, the loss of much time resulting. In 1893, the Commissioners, having a considerable sum of money available, determined to expend it in constructing a lock and weir to hold up the water, at and near Dartford, at a uniform level, sufficiently deep to allow barges to move about at any time—in fact, to form a floating harbour. For several reasons it was found unadvisable to place the lock lower down the river than the point at which it has been constructed. Its position being practically determined by local circumstances, the Author was in 1893 requested to advise on the mode of construction of the proposed works, which were in 1894 and 1895 carried out under his superintendence.

The lock is constructed on the right or east side of the river, where the bank was at a slope of about $1\frac{1}{2}$ to 1, and pitched with Kentish rag stone; the east wall of the lock was erected within the slope, and retaining walls about 210 feet long at each end were built to direct the channel. The weir was constructed between the west wall of the lock and the left-hand bank. The lock is 150 feet long, the gates being 25 feet wide in the clear, and the depth of water retained above the sill being 9 feet 6 inches. The weir is 90 feet long on the crest, which is fixed at 10 feet 6 inches above Ordnance datum—about 2 feet below ordinary spring-tides, but the top of the gate is 12 feet above datum; and this height was decided upon to allow of the weir being raised and the water being retained to that level if hereafter it should be found advisable. At high spring-tides the gates are submerged. The invert and walls of the lock and the retaining walls are constructed entirely of Portland-cement concrete, with the exception of the gate floors and chambers, which are faced with stock bricks. As it was anticipated that most of the concrete would have to be placed in the winter months, and would also at once be exposed to the action of the tide, it was made of exceptional richness, the ratio being from 4 to 1 to 6 to 1, according to the position in the work. The concrete in the invert and gate floors was gauged 4 to 1, the back wall 6 to 1, with a facing of 4 to 1, 12 inches thick; and the west wall, which was exposed on both faces, was gauged 5 to 1, the matrix being in every case clean gravel, most of which was obtained from the excavation, only

about 800 cubic yards of Thames ballast being used for the purpose. The pointing sills and hollow quoins are of cast-iron, the former being in three pieces, faced and bolted together, bedded and backed up with the concrete of the invert, and an oak sill for the gates to close against bolted on their face. The hollow quoins are in one-length, and are moulded to fit the heel-posts. Cast-iron was adopted for these parts of the work, with a view to expedite the work, and each sill, with its hollow quoins, was placed, bolted and bedded in a single tide.

It was originally contemplated to construct the lock in a whole-tide cofferdam consisting of a single row of timber sawn on all sides; but when the work was commenced, great difficulty was experienced in driving the guide-piles true, and the contractor obtained permission to adopt a method of construction which had previously been found successful, viz., dredging a trench 3 feet deep and placing in it 3-inch planks which are carried up on the outside of the piling, the trench being filled, and the planking backed up for a height of about 3 feet above the river-bed with good clay puddle. A long time was occupied in completing the dam, and when it was finished the water was allowed to rise on the outside. After about 6 feet head had been attained, the water poured in beneath the planking in such volume that it was found necessary to open the sluice to prevent a blow; and throughout the subsequent work, until the invert was complete, the water was let in when the tide had risen 3 feet and was allowed to run out through the sluice as the tide fell. The consequent delay, however, was not serious, as there is dead low-water for about seven hours every tide, so that eight hours' to nine hours' work was made out of the twelve hours, and the work was proceeded with night and day. The amount of pumping also was moderate, an 8-inch pump would clear the water after the tide left the work in less than half an hour, and when once clear it had only to be worked for a few minutes at intervals to entirely clear the sump, which was sunk 7 feet below the bottom of invert in the centre of the lock. The bottom was inserted in lengths varying between 15 feet and 25 feet, extending the full width of the work to the back of the walls; and the concreting of each length was usually completed in a couple of tides, the surface being carefully covered with boards, weighted down, before the water was admitted. As the latter came in slowly the cement was never washed out of the work. The 4 to 1 concrete set so hard in thirty-six hours that a pick would make little impression on it. Under the invert, 9-inch pipes led from the sump to the working faces, and these were thoroughly

grouted with thinly mixed concrete before the sump was finally filled. The brick facing was carried up simultaneously with the concrete walls. The width between the walls is 26 feet, but oak rubbing-pieces are inserted at intervals of 12 feet which project 6 inches, reducing the net width to 25 feet, corresponding with the gate openings. Copings of Roach Portland stone 3 feet by 1 foot, roughly hammer-dressed, are fixed on the top of all walls. The anchor-stones are of Portland, and are fine tooled to the radius of the heel-posts.

The gates are of oak framed with red wood, with wrought-iron sheathing 3 inches thick caulked with oakum and pitched. The mitre- and heel-posts measure 15 inches by 12 inches, and the rails as follows :—Bottom rail 12 inches square, second 12 inches by 9 inches, third 10 inches by 9 inches, fourth 9 inches by 9 inches, top out of 12 inches by 16 inches. The posts and top and bottom rails are rebated to receive sheathing.

There are two cast-iron sluices in each gate, one above the other, the bottom one being slung by wrought-iron slings from the upper one, so that both are lifted simultaneously by one set of gearing; their dimensions are, bottom 3 feet by 1 foot 9 inches, top 3 feet by 2 feet. The edges are planed, and they work in planed cast-iron guides. The heel-post pins are of steel, turned and fitted into holes bored in the pointing-sills, and on the heel of the heel-post a cast-iron socket is fixed with a brass bearing for the top of the pin. Cast-iron racers and rollers are provided, and a wrought-iron turned hoop is fitted to the heads of heel-posts, which are embraced by the wrought-iron anchor straps.

The situation did not admit of levers for opening and closing the gates, so cast-iron toothed segments were securely bolted to the top rail of the gate, into which pinions, worked by bevel gearing, engage. One man can easily open either of the gates in about forty seconds, though they weigh about 4 tons each. As it was necessary to avoid interference with the traffic on the river, the lock was first constructed and the gates and other works were completed while the traffic passed on the west side of the river. The cofferdam was then removed, and, the gates being kept permanently open, the vessels were passed through the lock while the weir was proceeded with.

The weir is of L shape in plan, to give sufficient length of crest to take the heaviest estimated land floods; but to guard against possible contingencies, four shuttles or sluices are provided, each 4 feet square, which can be lifted in pairs by machinery worked from a stage above high-water level. The weir consists of

two rows of piling 15 feet apart, the front being composed of guide-piles, 13 inches square, at 5 feet centres, filled in with 6-inch sheet piles grooved and tongued with steel, the back 10-inch square piles being spaced similarly and covered with 5-inch sheeting. Double rakers 9 inches by 6 inches connect the heads of the front and back row of piles, and these form joists for the apron of 3-inch close laid planking. The front row of sheeting is backed up with concrete, 4 feet wide at bottom, 2 feet at top and 3 feet high, and the space between piling is filled with heavy stones taken from the bank and closely hand-packed. The timber for the weir was subjected to the Gardenerizing preservative process.

The total cost of the lock was £4,016, and of the weir £410, or a total of £4,426. The price of the concrete was, it must be noticed, abnormally low, being, for 4 to 1 concrete below Ordnance datum, constructed to the curve of the invert, 10s. 6d. per yard; for 5 to 1, and 6 to 1, in walls built between shutters and planking, 10s. per yard, and 9s. 6d. per yard respectively. Nearly all the ballast was found in the ground, and the Portland-cement was supplied by the Dartford Portland Cement Company, whose works were connected with the lock by a narrow-gauge tramway. The cement was specified to stand a tensile stress of 380 lbs. per square inch at seven days; but from tests made constantly as the work proceeded, the average strength was 490 lbs. per square inch, and only in two cases was it as low as 400 lbs. The average strength at fourteen days was 568 lbs. per square inch, and in a few instances the strength at thirty-one days was 674 lbs. per square inch. All the castings and machinery were made at Dartford. Notwithstanding the advantages resulting from the works to craft-owners and owners of property and merchants at Dartford no additional tolls have been exacted by the Commissioners on account of the outlay entailed by the construction of the lock.

(*Paper No. 2941.*)

"Dimensions of Channels for Surface Drainage."

By CHARLES EDWARD LIVESAY, M. Inst. C.E.

IN a Paper on "Discharge from Catchment Areas,"¹ Mr. James Craig sought to demonstrate that the ordinary formula for maximum discharge was erroneously based solely on the area, and did not take into account the shape of the catchment basin. In the investigation of the formula adopted, Mr. Craig considered the basin as divided into convenient triangles, having their apexes, coinciding in the point of discharge of the whole country drained. Every catchment basin, however, in reality is finally drained by the bed of the principal stream or river, of a certain length and slope, into which various minor streams flow at different points, each tributary having its own basin, with its special configuration and area, the whole of the affluents constituting the total discharge from the catchment area.

Hitherto, it has been virtually concluded that the minor valleys of any catchment area are so closely connected as to be able to void their contents at a uniform rate; and, accordingly, it has been inferred that a river channel, at any point, must be sufficient to pass the aggregate uniform discharge of the whole area above it. This could only be true if the rainfall, which is supposed to occur simultaneously over the whole tract, does not run out of any outfall until the contents of all the upper valleys arrive at that point. This, however, can never be the case, as all the outfalls are discharging at the same time; and those situated near the exit of the main channel may have partially or wholly emptied their catchment areas before the flow from the upper outfalls can reach them. Any section, indeed, of the channel must be adequate to pass the aggregate volume to be drained above it in a certain period of time, but not in the sense ordinarily accepted, and assumed by Mr. Craig, of a sluice (where a single reservoir or tank is concerned), towards which the surface-water converges from all points at a nearly uniform velocity. The conditions are entirely dissimilar

¹ Minutes of Proceedings Inst. C.E., vol. lxxx, p. 201.

in a long drainage-channel; and it would probably be a closer approximation to the truth to say that any section of the channel must be capable of passing, not the whole, but the maximum of the combined discharges which may be flowing towards that section from above. If large enough to pass the maximum aggregate, it would be sufficient for any smaller volume which may run out before the maximum arrives. A consideration of the actual circumstances of a river flood will show that the above view must be truer to nature than Mr. Craig's assumption. The surface of the flood at any point in the course of the river rises gradually as the valleys nearest it discharge their contents, until the flood-level reaches its highest point, when the intensity of the flow indicates that the maximum of the combined discharges is passing; and when this has gone by, the level falls in consequence of the passage of combinations of smaller volume than the maximum, until the entire basin is emptied, and the flood subsides. By any other supposition, an average height and volume is arrived at, which can never be the result of actual experience, although it may be convenient for practical purposes to assume such conditions.

In the year 1885, when in charge of an irrigation division in India, the Author had to design certain alterations in the channel of a river to improve the drainage of over 200 square miles of the district of Cuttack, in Orissa; and he applied the principle of the above theory on that occasion. Although the works carried out according to his design have proved perfectly adequate under subsequent severe climatic tests, the Author cannot affirm that their success was due to the application of his theory. A description, however, of the method of its application in actual practice may conduce to beneficial results.

This tract of country comprises the greater portion of the land irrigated by the Kendrapara Canal of the Orissa Circle, Bengal Irrigation branch. The Kendrapara irrigation and navigation canal takes in its supply from the River Beropa, a tributary of the Mahanuddy, and is situated on two branches of the latter river. A minor irrigation canal, the Pattamundi, takes off the Kendrapara at its head, and is located on the right bank of the Beropa, the country concerned in the project lying between the two canals, Fig. 1, Plate 8. The Gobri River occupies the lowest bottom of the cultivated lands irrigated by the above canals, and receives the excess rainfall and waste canal-water, which it passes into the Gundakia River, a branch of the Beropa. The distributary channels from the Kendrapara Canal are

aligned on the highest ridges of the country, and divide the tract into a series of well-defined valleys, which are numbered consecutively from 1 to 15. The outfall of each is indicated by a circle enclosing its number, and a line marking its entry into the bed of the Gobri as improved. The Gobri takes its rise in No. 6 valley; but the portion which has been improved, consisting of Parts I, II, and III, extends from about a mile above the exit of No. 6 valley to the Kendrapara road bridge; and the map shows the mileage from the bridge upwards, Fig. 1, Plate 8. The length of the natural bed of the Gobri, within the limits mentioned, was 30 miles 3,950 feet, with a total fall of 22·65 feet, or an average slope of 0·73 foot per mile. By realignment in cutting off bends, the total distance has been reduced to 24 miles 3,600 feet, with an aggregate fall of 22·37 feet, or 0·90 foot per mile. It was found useless to improve the lower part of the Gobri, from the Kendrapara road bridge to its outfall on the Chota Bramini River.

The chainage of the survey and section commences at the Kendrapara road bridge; and up to 15 miles 17 chains the fall of the bed is 0·5 in 5,000, or about the same as the natural bed of the river, which in this length is wide and of considerable capacity. There were many loops which had to be cut through; but above 15 miles 17 chains it was found possible, by the straight Gungadhur diversion cut of less than 2 miles, to avoid a detour of 5 miles 670 feet along the old bed. From this point to the head the channel is 9 miles 2,900 feet, with a fall of 1·5 in 5,000. At the upper end of the Gungadhur diversion cut, a little below the 17th mile, the old bed of the Gobri was closed, which permitted the drainage from 33·95 square miles of country, between Nos. 6 and 8 distributaries, to pass down the old bed without interfering with the discharge from above, which meets it at the 15th mile, where the river is much wider and better adapted to carry a greater volume.

The total area drained by the Gobri River, as shown on the map, Fig. 1, Plate 8, is 206·74 square miles, including certain strips on the left bank of the Pattamundi Canal and the right bank of the Kendrapara Canal, which are drained by siphon culverts under those canals, the fall of the land in all cases of deltaic rivers like the Mahanuddy and Beropa, being inland from their banks. Nos. 1 and 2 areas lie between the Pattamundi Canal and the Beropa; No. 3 is a purely drainage bottom; and No. 4, originally a spill channel of the Mahanuddy River called the Sockania Nullah, had been closed at its head by the Kendrapara Canal. All these channels used to flow into the Beropa River; but on the construc-

tion of the Pattamundi Canal, it was thought best to divert their drainage into the Gobri by the Sookania diversion cut, thereby introducing into that stream the rainfall of a tract of 35.57 square miles, at a point where it had to carry the drainage of its own catchment area of 35.97 square miles. The land here is low, and the floods which stood over it for days together, used to destroy the crops every year until the improvement scheme was carried out, when Part I of the channel was embanked, and then served to pass the combined discharges of Nos. 1 to 4 from the Sookania cut into the deeper bed of the Gobri beyond. At the outfall of No. 5 valley, an inlet sluice was constructed in the embankment to pass the discharge of that area when the level of the flood in the embanked channel allowed it to enter.

The project was first designed to provide for the drainage of a rainfall of 4 inches over the whole tract in four days, the limit of time in which it is found that a submerged rice-crop does not suffer. This is equivalent to a discharge of 1 inch of rainfall in twenty-four hours; and the Table below, accordingly, indicates the volume in cubic feet per second to be dealt with in each valley. In order to determine how these quantities of water combine in the improved river channel, the length of this channel, 24.68 miles, was first developed into a straight line, plotted to the scale of $\frac{1}{2}$ inch to the mile, Fig. 2, Plate 8, in which the outfall of each valley is marked by a circle bearing its number. Nos. 1, 2, 3, and 4 are outside the channel; but as they all pass through the Sookania cut, they are shown in a direct line according to the distance of each outfall from the head. Nos. 9 and 10 debouch first into the old bed of the Gobri, isolated by the Gungadur diversion cut, and are exhibited according to their respective distances from the point of entry into the graded channel. The rest empty direct into the river, on the right or left bank respectively. To ascertain graphically how the discharges of the valleys would combine in the improved channel, it was necessary to adopt a method of representation. If the valleys were of uniform width, they could be represented by their lengths; but as they vary in breadth, they can only be compared by their discharges under the given rainfall. It was, therefore, assumed that each valley might be represented by the length of a line measuring $\frac{1}{2}$ inch for every 100 cubic feet per second of discharge; for example, No. 4 valley, having a discharge of 286 cubic feet per second, would be equal to 0.95 inch. The Table on pages 288 and 289, accordingly, exhibits the length of each valley in inches, and the other particulars of the scheme.

In order to bring the discharge of all the valleys into the graded channel, that valley must be selected for determining the extent the exits must be shifted to effect this object, the distance of whose outfall from the graded channel, together with the length representing its discharge, gives the greatest total length. This condition is fulfilled by No. 9 valley, which has therefore been selected for calculating the amount the points of exit of all the valleys must be shifted downstream to bring their discharge into the graded channel, since what suffices for No. 9 valley more than suffices for all the other valleys. In a case where the exits of all the valleys are situated immediately on the banks of the main drainage channel, the length of the longest valley would naturally be taken for the distance of progression. The discharge of No. 9 valley is 818 cubic feet per second, and is represented by 2·73 inches; but as the outfall is 2·85 miles from the graded channel, the discharge would take longer to enter the channel than if the outfall had been on its bank, and therefore adds 2·85 miles to the length of this valley. Assuming that all points of the flow in the river-bed and minor channels, as represented by their lengths, move at the same rate, it follows that to bring the whole length of No. 9 into the graded channel, its actual point of exit should be moved $2\cdot73 + 0\cdot95$, or 3·68 inches in the diagram of the discharges, Fig. 3, Plate 8. All the outfalls being supposed to be shifted similar distances to maintain their relative positions, the diagram, Fig. 3, Plate 8, shows in what combinations they occur in the improved channel.

For convenience of the design, the improved channel of the Gobri has been divided into three parts, namely:—Part I, from the head to 23 miles 4,300 feet on the embanked channel connecting the Sookania cut with the natural bed of the river; Part II, from 23 miles 4,300 feet to 15 miles 1,700 feet, including the Gungadhur diversion cut; and Part III, from 15 miles 1,700 feet to the Kendrapara bridge. Of the discharges of Nos. 1, 2, 3, 4, and 5 valleys, which must pass through Part I, No. 5 has run out before Nos. 3 and 4 have arrived; and No. 6 entering below these, the greatest combination for Part I is on section A B, consisting of Nos. 2, 3, and 4. For Part II, the section on C D is the maximum, comprising numbers 2, 3, 4, and 6 valleys. For Part III, No. 15 passes out alone; and of the three combinations which occur in this portion of the channel, on sections E F, G H, and I K, the first, E F, aggregates the maximum volume, including, as it does, Nos. 3, 4, 6, and 9 areas.

The diagram of discharges, Fig. 3, Plate 8, enables the natural rise

AREAS DRAINED BY THE GOBRI RIVER.

No.	Drainage Area.	Position of Outfall.		Area. Miles. Chains. Above Head.	Discharge of Rainfall of 1 inch in Twenty-four Hours.	Length, Inches.	Remarks.
		On Improved Channel.	Rank.				
1	Area drained by No. 1 siphon, Pattamundi canal, on left bank . . . }	..	8 13·28	2·38	63·97	0·21	1 inch of rainfall on 1 square mile in twenty-four hours = 26·88 cubic feet.
2	Area drained by No 2 siphon, Pattamundi canal, on left bank . . . }	..	2 33·00	4·15	111·55	0·37	
3	Drainage scheme No. 1, between Nos. 0 and 1 distributaries, Kendrapara canal	..	1 22·44	18·39	494·32	1·65	
4	Drainage scheme No. 2, between Nos. 1 and 4 distributaries, Kendrapara canal	..	1 22·44	10·65	286·27	0·95	
5	Area between Nos. 4 and 4 F distributaries, Kendrapara canal . . . }	24 6·50	R	..	5·49	147·57	0·49
6	Drainage scheme No. 3, between Nos. 4 and 6 distributaries, Kendrapara canal	23 43·0	R	..	35·97	966·87	3·22
7	Area under 6 D 3 C distributary, Kendrapara canal	23 5·50	R	..	2·22	59·67	0·20
8	Area under No. 5 distributary, Pattamundi canal, drained by No. 3 siphon	16 10·0	L	..	6·51	174·98	0·58
		16 10·0	R	..	1·59	42·73	0·14
							35·97
							—

9	Drainage scheme No. 4, between Nos. 6 and 8 and 8 distributaries, Kendrapara canal	15 17·0	R { 2·86 miles above river channel	30·45	818·49	2·78			Total area	•	Square Miles.			
10	Area between Nos. 8, 8 K, and 8 H distributaries, Kendrapara canal	15 17·0	R 1 20·00	3·50	94·08	0·31			Less No. 10	•	83·95			
11	Area under No. 7 distributary, Patta-mundi canal and south, including area drained by Nos. 4 and 5 siphons, Patta-mundi canal	9 43·7	L ..	14·02	376·85	1·26					3·50			
12	Area between Nos. 8, 8 I, and 8 I' distributaries, Kendrapara canal	7 19·0	R ..	6·00	161·28	0·54								
13	Drainage scheme Nos. 5 and 6, between Nos. 8 and 11 distributaries, Kendrapara canal	6 35·0	R ..	39·88 *	1,071·97	3·57								
13½	Between Nos. 8, 8 K, and River Gobri	13 7·92	R ..	1·50	40·32	0·13								
14	Area drained under part of No. 8 distributary, Pattamundi canal	6 9·0	L ..	5·99	162·01	0·54								
15	Drainage scheme No. 7, between Nos. 11 and 13 distributaries, Kendrapara canal	0 40·0	R ..	18·05	485·18	1·62								
	Total area	.. ..	.. ..	206·74										

and fall of the river in the first mile of its channel to be understood. The first rise takes place by the discharge of No. 15, which runs out alone, and leaves the bed in its normal condition for a short time. Then the combination of Nos. 14, 13, and 12, causes another elevation, followed by a fall when No. 13 only is flowing. The level again increases by the arrival of Nos. 11 and 13½, in conjunction with No. 13, succeeded by another subsidence when this has passed, and so on until the flood attains its greatest height by the passage of the maximum combination of Nos. 3, 4, 6, and 9 on cross-section E F. The flood then gradually subsides with the discharge of the confluence of Nos. 1 and 6.

The following volumes have to be provided for in the several parts :—

PART I.

No. 2 valley ; area,	4·15	square miles ; discharge,	111·55	cubic feet.
No. 3 " ; "	18·89	" " ; "	494·32	" "
No. 4 " ; "	10·65	" " ; "	286·27	" "
Total area, <u>33·19</u> square miles ; discharge, <u>892·14</u> cubic feet.				

PART II.

All above, area,	33·19	square miles ; discharge,	892·14	cubic feet.
No. 6 valley, " 35·97	" " ; "	" " ; "	966·87	" "
Total area, <u>69·16</u> square miles ; discharge, <u>1,859·01</u> cubic feet.				

PART III.

All above, less No. 2 ; area,	65·01	square miles ; discharge,	1,747·46	cubic feet.
No. 9 valley ; " 30·45	" " ; "	" " ; "	818·49	" "
Total area, <u>95·46</u> square miles ; " <u>2,565·95</u> cubic feet.				

Comparing, however, these volumes with those actually observed in the River Gobri after an abnormal rainfall, they were found to be totally inadequate. On the 3rd August, 1880, the following quantities of rainfall were gauged : at Kendupatna, near the centre of the tract, 10·53 inches ; at Kendrapara, at the east end of the tract, 6·70 inches ; at Marsaghai, at the thirty-ninth mile of the Kendrapara Canal, 5·75 inches ; at Byree, on the high-level canal, 6·90 inches ; at Indpur, near the Pattamundi Canal, 3·30 inches ; and at Acquapudda, about 23 miles north-east of Indpur, 3·20 inches. These records show the widespread extent of the precipitation. For the tract now being dealt with, it will suffice to take a mean between the first and second

returns, amounting to 8·61 inches in twenty-four hours. The discharge of the Gobri immediately above the Kendrapara road bridge on that occasion was found to have been 5,881·40 cubic feet per second, or more than double that determined for Part III of the scheme. Although this circumstance does not invalidate the truth of the Author's theory, it very clearly demonstrates that the assumption of 1 inch of rainfall passing in twenty-four hours was very far from being correct. Taking the catchment area of Part III to be 95·46 square miles, 5,881·40 cubic feet per second as the actual volume to be provided for, and κ the rainfall which probably runs off, $\frac{95\cdot46 \times 5,280 \times 5,280 \times \kappa}{60 \times 60 \times 24 \times 12}$

= 5,881·40; and $\kappa = 2\cdot29$ inches. For a rainfall, therefore, of 8·61 inches, it appears necessary to conclude that 2·29 inches run off in twenty-four hours. This is not surprising, considering that the country at that time of the year must be saturated with rain-and canal-water, and incapable of absorbing much. The run-off would be much greater if it were not held back to a considerable extent by standing paddy crops and the distributary banks. The natural section of the Gobri River in Part III was amply sufficient for the passage of the observed discharge; and beyond cutting off bends or loops, no alteration was required in this portion of the channel.

By another observation of the river at 19 miles 41 chains, the discharge was found to have been 3,201·20 cubic feet per second, and taking the catchment area of Part II, 69·61 square miles, $\frac{69\cdot61 \times 5,280 \times 5,280 \times \kappa}{60 \times 60 \times 24 \times 12} = 3,201\cdot20$; and $\kappa = 1\cdot83$ inches. To

pass this volume through the Gungadhur diversion cut, a section of 70 feet base, with side slopes of 2 to 1, was given. This section, with a depth of 9 feet and a fall of 1·5 in 5,000, provides for a calculated velocity of 3·99 feet per second, and a discharge of 3,160·08 cubic feet per second.

Above Part I, the observed discharge of the Sookania cut was found to be 1,023·21 cubic feet per second. Taking the catchment area of Part I at 33·19 square miles, $\frac{33\cdot19 \times 5,280 \times 5,280 \times \kappa}{60 \times 60 \times 24 \times 12}$

= 1,023·21; and $\kappa = 1\cdot38$ inches. The section given to carry this volume in the embanked channel of Part I was, base 34 feet and side slopes 2 to 1, which, with a depth of 7 feet and a fall of 1·5 in 5,000, gives a velocity of 3·14 feet, and a discharge of 1,055·04 cubic feet per second. As, however, a depth of 9 feet was found necessary in Part II, the same depth was adopted in

Part I, the banks being constructed 12 feet above the bed, or 3 feet above the water-level, in case the level should be raised by the swollen state of Part II. An outlet sluice was also built in the right embankment, to drain off any rainfall which might accumulate on the low land behind it before the flood-level in the embanked channel should fall low enough to admit of its passage into the main river. Since the scheme was carried out, several abnormal falls of rain have taken place at Cuttack, quite as heavy as the one recorded in August, 1880; but no damage has occurred to crops in the cultivated lands in the valley of the Gobri River, indicating that the preventive measures have been successful.

To apply the theory formulated in this Paper, it will always be necessary to define the extent of each minor valley in the catchment basin of a drainage area, and to collect accurate information of the rainfall to be dealt with. For the configuration of the minor valleys, with good maps, it will doubtless be a sufficient approximation to assume the watershed between two minor valleys to lie midway between the tributary streams; but if greater exactness were required, a series of cross-sections at long intervals from one stream up to the dividing ridge would demarcate the ridge, or the ridge itself might be surveyed. For the rainfall data, observations would have to be taken as to the loss by evaporation and absorption in different localities, for which closer and more discriminating observations are needed, as very little is known of this loss. There must be wide differences due to the land being cultivated or unbroken, forest or grass, rocky or a mixture of all descriptions; and only actual observation would show what portion of the run-off should be provided for. When, however, the surface-drainage of towns is considered, very accurate data would be available for each block to be dealt with, as to extent and configuration, as well as to meteorological conditions of the whole area; and it is probable that, in these cases, the theory advanced may be applied with advantage, especially as regards the safe and economical removal of storm-water.

The Paper is illustrated by a plan and two diagrams, which are reproduced in Plate 8.

(*Paper No. 2962.*)

“Garbage Disposal at St. Louis, Mo., U.S.A., by the
Merz System.”

By JOHN POWNALL, Assoc. M. Inst. C.E.

THE problem of garbage disposal has in recent years much exercised the authorities of the larger cities of the United States; and the most economic and efficient method of disposition of city waste has formed the subject of varied and costly experiment. Garbage from all sources, should, especially in the summer months, be collected daily; and hermetically-sealed receptacles should be used to prevent the escape of offensive odours whilst it is in transit to the works. At no point in the plant should steam or vapours be allowed to escape whilst the garbage is in process of reduction or cremation, and ample provision should be made for the destruction, by combustion, of all gases liberated during the operation. Among the reduction or utilization systems, or the cremation or incineration processes, may be classed all the methods for the disposal of city refuse used in America.

The plant at St. Louis, Mo., for the reduction and utilization of garbage by the Merz system, has been in use for four years, and during that time has given practical demonstration of the valuable results to be obtained from this method of treatment. The City of St. Louis is situated on undulating prairie country on the west shore of the Mississippi river in eastern Missouri, and has a population of 500,000. It extends along the river for a distance of 14 miles, with an average breadth of 7 miles. For the collection of garbage it is divided into three districts, from each of which the material is removed twice per week, between October to April, and three times weekly during the summer months. From hotels and restaurants it is collected daily throughout the year. In October, 1891, the City of St. Louis entered into a contract with the St. Louis Sanitary Company for the disposal of the garbage of the city by the Merz system. The contract extends over a period of ten years, and stipulates that the City shall deliver the garbage at the Company's works and shall pay the sum of 7s. 5d. per ton to the Company for all garbage delivered up to 100 tons per day;

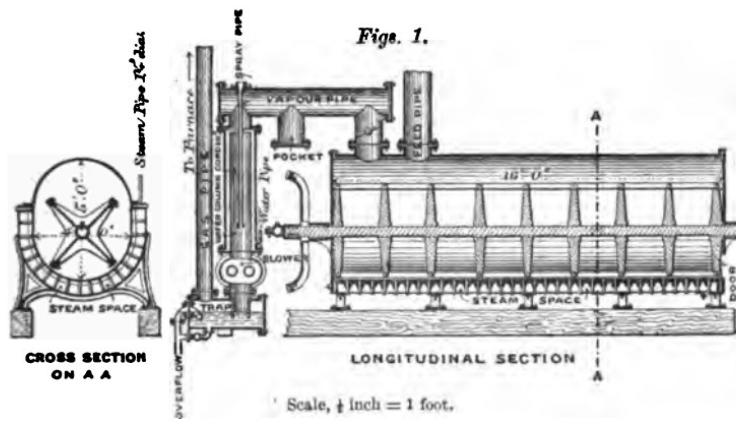
any quantity in excess of that amount is to be treated by the Company free of charge.

The Merz system is an abstraction process in which a volatile hydro-carbon solvent is utilized. In the present St. Louis plant naphtha is employed, and the products are grease and a residual fertilizer of some value. The former is an agent in the manufacture of soap, and the latter is in demand on account of its manurial properties at prices varying between 18s. and 30s. per ton. The grease realizes 1½d. per lb.

The principal works of the Company are favourably situated in a ravine on the south side of the city within the municipal limits and with siding accommodation to the Iron Mountain and Southern Railway. There is also a subsidiary plant on the north side of the city for the treatment of dead animals and the excess of ordinary garbage when the main works are surcharged, during the months of July, August and September. The quantity of material treated during January, 1895, was 2,749 tons, or 88·7 tons daily. It increased to 7,077 tons in September, 1895, or 235·9 tons daily. The receiving-room at the works is on the second floor, and is approached by an inclined trestle-roadway from the street. The wagons are weighed on entering, and the contents are discharged into receiving-tanks through the doors in the top. Whilst the tanks are being filled they are kept closed with wooden covers, but when they are full these are replaced by cast-iron doors, tightly closed. Special care is taken to have all wagons thoroughly washed with hot water before leaving. The large quantity of waste iron and other foreign matter renders a re-handling of the garbage necessary for sorting purposes after its reception in the receiving-tank, otherwise the process of reduction would be automatic throughout. There are eight steel receiving-tanks in use, each 8 feet 6 inches in diameter by 14 feet deep. In the bottom of each is a door, from which the garbage is drawn as required, and, after the sorting operation, is fed into the dryers through 12-inch feed-pipes. In the reduction-room there are eighteen driers, consisting of elliptical-shaped chambers, *Figs. 1, 4* feet wide, 5 feet high and 16 feet long inside, supplied with steam-jackets over two-thirds the perimeter on the lower side. The inner shell is of cast iron, varying in thickness between 2 inches at the bottom and 1 inch at the top. The garbage is agitated by a central shaft and reel revolving at a speed of fifteen revolutions per minute, and the condition of the material is ascertained from time to time during the process of reduction by means of a test-hole in the rear. A period of 4 hours or 5 hours is required

to complete the drying operation, and during that time the garbage is heated to a temperature of 250° F. It is found by observation that ordinary crude garbage loses from 65 per cent. to 75 per cent. of its original weight during the process of drying; it will readily be seen, therefore, that the most expensive and difficult operation in connection with a plant of this kind lies in the extraction of water from the crude material. The vapours driven off pass to water-column condensers, the condensed gases passing to the sewer, and the uncondensed vapours being conveyed through pipes to the retorts in the boiler furnaces where they are consumed. The dried material is discharged automatically from the

Fig. 1.



GARBAGE DRIER USED IN THE MERZ SYSTEM.

rear of the dryer into a cast-iron screw conveyor, working on a central shaft in a cast-iron box. This conveyor traverses the entire length of the reduction-chambers in rear of the dryers. At the end of the conveyor is an elevator carrying the garbage to the extractor-room.

In this room, which occupies a section of the second floor, there are four extractors, consisting of steel cylindrical tanks of similar construction to the receiving-tanks, with the addition of the necessary appliances for regulating the admission of the solvent and steam. Each tank is provided with a perforated false bottom, between which and the lower faces of the tank is placed a coil, to apply a gentle heat to the material under treatment. The garbage is allowed to soak for a period of from 2 hours to 4 hours, until all grease, oil and fatty matters are taken up by the solvent, and at the end of that time the solution of naphtha and grease is drawn

off. The naphtha is vaporized and passes to condensers on the upper floor, where it is condensed and stored for subsequent use; the grease after being purified is ready for shipment. The process is automatic and continuous.

The boiler-room contains a battery of twelve 125-HP. horizontal tubular boilers, mounted independently. Each boiler is suspended from six cast-iron columns by $1\frac{1}{4}$ -inch hanger-bolts secured to lugs on the boilers. Cast-iron retorts are built in the furnaces for consuming the vapours carried from the reduction-room. The furnaces are connected with a wrought-iron smoke-stack 10 feet in diameter and 175 feet high. The main steam-pipe is 16 inches in diameter. In the engine-room there is a 250-HP. Corliss engine, and two smaller engines of 60 HP. and 36 HP., used respectively for electric lighting and ventilation. It will readily be understood that for works of this character the consumption of water is very large. The quantity required generally exceeds 500,000 gallons per day, and to provide for this supply there are in constant use three duplex pumping-engines with a combined capacity of 750,000 gallons daily. The supply is obtained from an artesian well 1,250 feet deep. In the mill-room there are three screens and one 52-inch mill for grinding the screened material. The separating-screen is of No. 16 sheet-steel, perforated with 2-inch holes. The finishing-screens are of the same material, but perforated with $\frac{1}{8}$ -inch holes, four to the inch.

To facilitate sacking and shipping, the finished fertilizer is distributed at various points of the shipping-room by means of a drag, composed of two strands of link belting with suitable hardwood slats bolted on at intervals of 28 inches. The strands are worked by sprocket-wheels at each end. There are two lateral lines of 12-inch spiral conveyors running at right-angles to the drag. Exhaust-fans are placed at all necessary points, with funnels over each extractor and receiver to take off the vapours arising from the garbage and for the general ventilation of the plant.

The walls are of brick on stone foundations, and the roof is of iron or tar and gravel. Ample protection is provided against fire, both in the construction of the buildings and by the installation of automatic sprinklers.

The Paper is accompanied by three drawings, from a selection of which the *Figs.* in the text have been prepared.

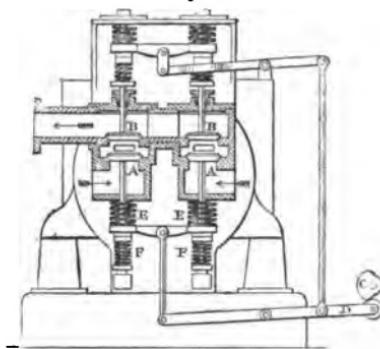
(Paper No. 2990.)

"Experiments on a Two-Stage Air-Compressor."

By JOHN GOODMAN, Wh.Sc., Assoc. M. Inst. C.E.

EXHAUSTIVE trials of heat-motors are now universally recognized as the only methods of analyzing the sources of loss in efficiency in the conversion of heat into work. Similar methods applied to air-compressors also yield data of the greatest possible value; it is to a description of such tests, and of the methods of reducing the results, that the following Paper is devoted.

The compressor upon which the trials were made is of the horizontal type, with a stroke of 18 inches, the air-cylinders being arranged in tandem with the steam-cylinders. The latter are each 10 inches in diameter, and are fitted with Meyer variable-expansion slide-valves. The piston-rods are 1·875 inch in diameter, and are carried through the back covers to the air-cylinder pistons. The air-cylinders are arranged on the two-stage principle, so that the air is drawn into the low-pressure cylinder, 13·5 inches in diameter, and is compressed and delivered, through an intercooler, with a surface of 29 square feet, into the high-pressure cylinder, 9·25 inches in diameter, where it is again compressed and delivered into the mains. Each air-cylinder is water-jacketed in order to carry off the heat evolved during the compression. The air is admitted into the cylinder, and delivered, through West-Jenkins valves. It enters the valve-box as shown by the arrows, *Fig. 1*, and passes to the cylinder by the mushroom inlet-valves, AA, each of which is provided with two springs on the valve-stem. The lower one, F, tends to open the valve, while the upper one, E, being much

Fig. 1.

stronger, tends, when free, to keep the valve to its seat. Just when the piston reaches the end of the compression-stroke, the cam, C, forces down the end of the lever, D, and compresses the closing spring, E, thus relieving the valve of the downward pressure of the spring. The lower opening spring, F, then opens the valve immediately the pressure above it has fallen to that of the atmosphere, and remains open until the cam again lowers the lever, and allows the stronger closing spring to come into action, and brings the valve back to its seat just as the piston reaches the end of the stroke. The valve is thus forced wide open at once, and remains so without offering any appreciable resistance to the incoming air. The outlet valves, B B, are actuated in a similar manner. The function of the lower and weaker springs is to balance the weight of the valves, and thus allow them to open with the smallest possible difference of pressure on the two sides. The function of the upper and stronger springs is to bring the valves smartly back to their seats without chatter or blow.

The clearance in the steam-cylinders amounted to 102 cubic inches, or 7·2 per cent. of the working volume, and to 138 cubic inches and 65 cubic inches, or 5·4 per cent. of the working volume, in the low- and high-pressure air-cylinders respectively. In order to reduce the detrimental effects of clearance, the air-cylinders are provided with "by-pass" grooves at each end of the stroke, by means of which the high-pressure air entrapped in the clearance space at each end of the stroke is transferred to the other side of the piston, *i.e.*, from where it is a distinct evil—by preventing the suction-valves from opening at the commencement of the return stroke—to where it is a gain, *i.e.*, on the compressing side of the piston, thus ensuring a larger volume of air being taken in and delivered. The equivalent clearance, allowing for the by-pass, is 69·6 cubic inches, or 2·7 per cent. of the working volume. The volumetric efficiency is thereby increased, but, on the other hand, there is a slight waste of power. The volume swept through by the low-pressure air-piston per stroke was 1·476 cubic foot, the volume of air that should have been drawn in, allowing for the clearance and by-pass, being 1·452 cubic foot.

For the purposes of this test, all the air delivered from the high-pressure cylinder was passed through a final cooler, with a surface of 10 square feet, consisting of rows of pipes placed in water, on its way to three large receivers, each with a volume of 148 cubic feet, for measuring the quantity of air delivered. Readings were taken every fifteen minutes. Crosby indicators

were used at each end of the air-cylinders, and Tabor indicators for the steam-cylinders. The speed was measured by a Schäffer-Budenberg counter. The circulating water from the jackets, intercooler, and final cooler was allowed to run into separate barrels, which were lifted by an overhead traveller and weighed at the end of the trial. The inlet and outlet temperatures were measured by thermometers placed in the flowing water. A wet-and dry-bulb hygrometer was placed close to the compressor to measure the quantity of moisture in the air, the dry bulb furnishing the temperature of the air supplied to the compressor. Thermometers passing through stuffing-boxes were placed with their naked bulbs in contact with the air in the pipes between the low-pressure cylinder and the intercooler; in each of the passages leading from the intercooler to each end of the high-pressure cylinder; between the high-pressure cylinder and the final cooler; between the final cooler and the receiver; and in six places on the outside of the receivers, the latter being covered over with cotton waste. The latter were only used for special trials, in which the readings were taken at the beginning and end of the experiment. The volume of the pipes between the compressor and receiver was 1.15 cubic foot, and that of the pipes and connections between the delivery-valves of the low-pressure cylinder and the suction-valves of the high-pressure cylinder, including the spaces at the end of the cooler and the volume of the tubes of the intercooler, was 3.01 cubic feet. The height of the barometer was taken at the beginning and end of the trial.

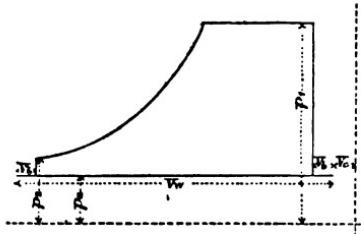
Two series of experiments were made to ascertain the volumetric efficiency of the compressor, *i.e.*, the ratio of the volume of the air actually delivered to the volume displaced by the low-pressure air-piston. In the first, the compressor delivered the air into one of the three receivers, at a constant pressure of 60 lbs. per square inch above the atmosphere, from which it was kept blowing off through an outlet-valve into the atmosphere, the second and third receivers being at atmospheric pressure at the beginning of the test. At a given signal the outlet-valve was closed, and the air escaping from the first receiver was shunted into the second and third receivers, and the number of strokes made by the compressor while it was raising the pressure up to 60 lbs. per square inch in these receivers was carefully noted. In the second series the three receivers were at atmospheric pressure at the start, and the compressor discharged its air through an outlet-valve direct into the atmosphere. At a given signal the outlet-valve was closed, and the air delivered into the three receivers until the

pressure had been raised to 60 lbs. per square inch above the atmosphere. The number of strokes made by the compressor in thus raising the pressure was carefully noted as before. Two experiments were made in each series, and agreed almost perfectly with one another, and with previous results obtained by Mr. Jenkins, manager of the Company, to whom the credit of this method of measuring the air is due. In previous tests made by the Author the latter method had always been adopted. It was feared, however, that it gave unfair results in favour of the compressor, as leakage past the valves and pistons would be less at the beginning of the test, when the pressure was low, than at the high pressure. The first method much more nearly approaches the exact conditions under which the air is delivered in practice. During the trial the pressure in the receivers was kept at 60 lbs. per square inch, and the outlet-valve discharged into a long length of $6\frac{1}{2}$ -inch piping, at the end of which a 6-inch Davis anemometer was placed to ascertain to what degree of accuracy they could be relied upon. The results of the tests are shown in the Appendix. The area of the pipe less the area of the anemometer-dial and case was 0.189 square foot. The following results were obtained :—

Actual Volume passed.	Volume by Anemometer.
Cubic Feet.	Cubic Feet.
184	181
185	186
164	198
2,250	2,142

Just before "by-passing" occurs there is a volume of air $= (V_w + V_c)$ at the pressure p_1 , Fig. 2, on the pressure side of the piston, and there is a volume of air $= (V_w - V_c + V_s)$ on the suction side of the piston at the pressure p_a , where V_w is the working volume of low-pressure piston, 2,552 cubic inches, V_s the volume, 17.72 cubic inches, swept by the piston between the end of its stroke and when it closes "by-pass" grooves (in this case the grooves project

Fig. 2.



$\frac{1}{2}$ inch beyond the piston when it is at the end of its stroke), V_c the clearance volume, 138 cubic inches, p_a the atmospheric pressure (14.82 lbs. per square inch), and p_1 the final pressure to

which the air is compressed in the low-pressure cylinder, 36·4 lbs. per square inch. Then, when "by-passing" occurs there will be a volume ($V_b + 2 V_c$) at a pressure p_2 ; hence, by Boyle's law—

$$p_1 (V_b + V_c) + p_a (V_a - V_b + V_c) = p_2 (V_a + 2 V_c)$$

or,
$$p_2 = \frac{p_1 (V_b + V_c) + p_a (V_a - V_b + V_c)}{V_a + 2 V_c};$$

but as the equivalent clearance, V_e , produces the same effect as the actual clearance and "by-pass"—

$$V_e p_1 = (V_b + V_c) p_2, \text{ or } V_e = \frac{(V_b + V_c) p_2}{p_1}.$$

But the suction-valves do not begin to open until the pressure p_2 falls to p_a . Hence the piston must have swept through a volume V_e after passing the by-pass grooves. Then—

$$V_e p_2 = (V_e + V_c) p_a, \text{ or } V_e = \frac{V_e (p_2 - p_a)}{p_a}.$$

The suction-valves close immediately the piston uncovers the by-pass grooves towards the end of the stroke. Then, assuming that the valves open and close exactly at the right instant, the volume of air drawn in by the piston at each stroke is $V_e = V_a - 2 V_b - V_c$. Substituting the numerical values given, $V_e = 2,510$ cubic inches, or $1\cdot452$ cubic foot. This volume V_e is the maximum that can possibly be drawn into the compressor.

The indicator cards were measured with an Amsler planimeter. The mechanical efficiency was obtained from the ratio—

$$\frac{\text{I.H.P. in air cylinders}}{\text{I.H.P. in steam cylinders}} \times 100 = \frac{23\cdot82}{29\cdot37} = 81\cdot1 \text{ per cent.}$$

The pressure in the air-receivers was measured with two new Schäffer and Budenberg pressure-gauges. The mean reading by the one was 60·85 lbs. per square inch, and by the other 61·30 lbs. per square inch, the mean of the two being 61·08 lbs. per square inch. The absolute pressure is $61\cdot08 + 14\cdot82 = 75\cdot90$ lbs. per square inch.

In a perfect air-compressor the air would be drawn in at atmospheric pressure, then isothermally compressed to the desired pressure, and finally delivered at the pressure in the mains. In such a case the compression would follow Boyle's law, viz., that $p \cdot v = \text{constant}$, and the compression curve would be a hyperbola.

The work done in foot-lbs. per stroke in compressing and delivering the air would then be $p_a V_a \log \frac{p_1}{p_a}$, where p_a is the atmospheric pressure in lbs. per square foot, V_a the volume of air in cubic feet drawn into the low-pressure cylinder, and p_1 the pressure in the mains or receiver, also in lbs. per square foot. From the results given above and in the Appendix, the isothermal work done per stroke is $14.82 \times 144 \times 1.452 \times \log \frac{75.9}{14.82} = 5,067$ foot-lbs.

The work actually done per stroke was

$$\frac{\text{The I.H.P. (air)} \times 33,000}{\text{Number of strokes made per minute}} = \frac{23.82 \times 33,000}{130} = 6,047 \text{ ft.-lbs.}$$

The efficiency of the compression process is, therefore, $\frac{5,067}{6,047} \times 100 = 83.8$ per cent.

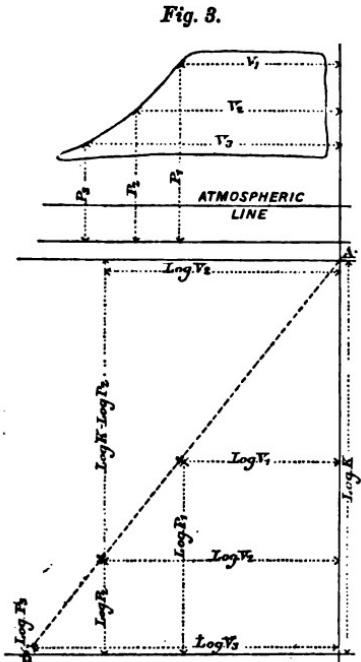
If no heating of the air took place during compression n would equal 1, i.e., the process would be isothermal, and if none of the heat due to the compression were conducted away n would be 1.408 for dry air, i.e., the process would be adiabatic. The value of n gives a measure of the efficiency of the jacket cooling. It is obtained from the slope of the line $a b$ in the logarithmic diagram, Fig. 3, thus:—

$$\log K - \log p = n \log v; \\ \log p + n \log v = \log K;$$

$p v^n = K$. The slope of the line $A B$ for the low-pressure diagrams was 1.27, and 1.28 for the high-pressure diagrams. Combined indicator diagrams are shown in Fig. 4.

In the first series of tests the air was delivered at constant pressure, the joint capacity of the two receivers (V_r) being

296 cubic feet. Eight hundred and eighty-one strokes were made by the compressor, while filling the two receivers, the mean



temperature of the air in which (T_1) was $529 \cdot 4^\circ$ absolute. The calculated temperature of air during the test at the beginning of the compression in the low-pressure cylinder was $532 \cdot 2^\circ$ absolute. The atmospheric pressure (P_a) was $14 \cdot 82$ lbs. square inch; and the final pressure in the receivers (P_1) was $74 \cdot 8$ lbs. square inch absolute.

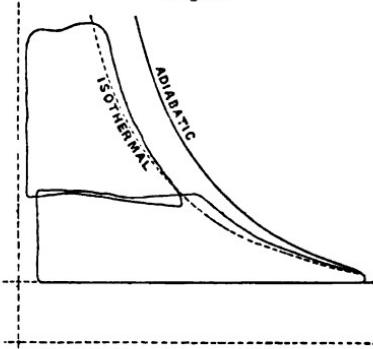
The volume of air delivered by compressor at atmospheric pressure is $V_w N E$, where N is the number of strokes made by the compressor while filling the receivers, and E is the volumetric efficiency, i.e.,

$$\frac{\text{Vol. of air delivered per stroke}}{\text{Working volume}}$$

The volume of air already in receivers is V_r ; and, as $\frac{PV}{T} = a$ constant, $\frac{P_a(V_w N E + V_r)}{T_a} = \frac{P_1 V_r}{T_1}$, where T_a is the atmospheric temperature, P_1 the pressure, and T_1 the temperature in the receiver, or $T_1 P_a V_w N E = P_1 V_r T_a - T_1 V_r P_a$ and $E = \frac{V_r (P_1 T_a - P_a T_1)}{P_a V_w N T_1}$ (on the full working vol.), or $E_o = \frac{V_r (P_1 T_a - P_a T_1)}{P_a V_w N T_1}$ (allowing for clearance and by-pass). Substituting the numerical values $E = 91 \cdot 7$ per cent. and $E_o = 93 \cdot 2$ per cent., the results hardly do justice to the compressor, because the air was heated in entering the low-pressure cylinder; hence the temperature at the beginning of the compression should be substituted for the T_a in the last expression, so that $E = 92 \cdot 8$ and $E_o = 94 \cdot 3$ per cent.

In the second series the air was delivered under a pressure varying between 0 to 60 lbs. per square inch above the atmosphere. The joint capacity of three receivers and connections between HP. cylinder and receivers was $445 \cdot 15$ cubic feet. The volume between the low- and high-pressure cylinders was 3 cubic feet at a pressure of $36 \cdot 4$ lbs. per square inch, or, corrected for pressure, $\frac{3 \times 36 \cdot 4}{74 \cdot 8} = 1 \cdot 46$ cubic foot. The volume of the high-pressure cylinder was $0 \cdot 71$ cubic foot; the total capacity reduced to a common pressure (V_r^1) was thus $447 \cdot 32$ cubic feet. The

Fig. 4.



compressor made thirteen hundred and two strokes while filling the three receivers and connections; the mean temperature of air in the receivers (T_1) was $534 \cdot 3^\circ$ absolute. The calculated temperature of air during test at the beginning of the compression in the low-pressure cylinder was $532 \cdot 2^\circ$ absolute. Substituting these numerical values in the equation given above $E = 92 \cdot 7$ per cent. and $E_c = 94 \cdot 2$ per cent., and allowing for the heating of the air on entering the low-pressure cylinder $E = 93 \cdot 8$ and $E_c = 95 \cdot 4$ per cent.

Adhering to the notation given above, the volume of air delivered per I.H.P. hour when corrected for the delivery

$$\text{temperature was } \frac{(60 N V_c E) \frac{T_c}{T_1}}{\text{I.H.P.}}$$

On substituting the numerical

values given in the Appendix the volume is $358 \cdot 2$ cubic feet, or, if no allowance were made for the volumetric efficiency of the compressor, as is so often (but erroneously) done, $390 \cdot 5$ cubic feet.

According to Glaisher the temperature of the dew-point may be obtained by multiplying the difference between the temperatures of the wet and dry bulb by a constant depending on the temperature of the air at the time of observation and subtracting the product thus obtained from the last-named temperature. The constant in this case is $1 \cdot 8$, hence the dew-point is $66 \cdot 37 - (66 \cdot 37 - 64 \cdot 58) 1 \cdot 8 = 62 \cdot 07^\circ$ F. The quantity of moisture in saturated air at different temperatures has already been given by Mr. Lightfoot.¹ The percentage of moisture present in saturated air at 62° F. is $1 \cdot 18$ lb. per

$$100 \text{ lbs. of dry air. There are } \frac{12 \cdot 387 \times 523}{493} = 13 \cdot 14 \text{ cubic feet}$$

$$\text{of air per lb. at } 62^\circ \text{ F.; therefore there are } \frac{0 \cdot 0118}{13 \cdot 14} = 0 \cdot 000898 \text{ lbs.}$$

$$\text{of moisture in 1 cubic foot at } 62^\circ \text{ F., or } \frac{0 \cdot 000898 \times 534 \cdot 34}{523}$$

$= 0 \cdot 00092$ lbs. at the temperature of the air at the beginning of compression in the low-pressure cylinder, and at that temperature

$$\text{there are } \frac{12 \cdot 387 \times 534 \cdot 34}{493} = 13 \cdot 43 \text{ cubic feet of air per lb., or}$$

$$1 \text{ cubic foot weighs } \frac{1}{13 \cdot 43} = 0 \cdot 07446 \text{ lbs.}; \text{ hence the total weight}$$

of 1 cubic foot of the air and moisture $= 0 \cdot 07538$ lbs., or there

$$\text{are } \frac{1}{0 \cdot 07538} = 13 \cdot 26 \text{ cubic feet per lb. of moist air. In 1 lb.}$$

¹ Proceedings of the Institution of Mechanical Engineers, 1881, p. 122.

of air there is 98.82 per cent. of air and 1.18 per cent. of moisture. The specific heat of water vapour is 0.48, and dry air 0.238. Hence the specific heat of the moist air is $0.9882 \times 0.238 + 0.0118 \times 0.48 = 0.241$. The number of thermal units given up by the air to the water in the intercooler = $1,177 \times 43.27 = 50,930$. The amount of air passed through the intercooler was 2,389 lbs. The fall of temperature of the air in passing through the intercooler was $173 - 79.63 = 93.37$.

Hence the specific heat of the air was $\frac{50,930}{2,389 \times 93.37} = 0.2283$.

From the final cooler the specific heat of the air = $\frac{15,660}{2,389 \times 28.54} = 0.2297$. The compressor delivered $1.476 \times 0.917 = 1.354$ cubic feet of moist air per stroke, or $\frac{1.354}{13.26} = 0.1021$ lbs. per stroke.

There were $65 \times 2 \times 60 \times 3 = 23,400$ strokes made during the trial, hence the weight of air compressed was $23,400 \times 0.1021 = 2,389$ lbs. The air, on passing through the inlet-valves, is heated somewhat and expanded, and consequently the compressor does not take in the full displacement of air calculated on the outside temperature. This action partially accounts for the difference between the actual and the calculated output of a compressor. A direct measurement of the temperature of the air at the beginning of compression in the low-pressure cylinder is impossible with present appliances. It can, however, be approximately arrived at by calculation from the known temperature at which the air left the cylinder. It has

been shown in works on thermodynamics that $T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$,

where T_2 is the absolute temperature at the beginning of the compression process, when the pressure is P_2 , and T_1 is the absolute temperature when the pressure is P_1 . Substituting the numerical values from the Appendix,

$$\begin{aligned} T_2 &= 634 \left(\frac{16.26}{36.4} \right)^{\frac{0.27}{1.27}} \\ &= 534.34 \text{ absolute.} \\ &= 73.74^\circ \text{ F.} \end{aligned}$$

The quantity of heat credited to radiation at first sight appears to be much larger than it ought to be; but when the amount of surface from which radiation takes place is considered, the loss does not appear abnormal. From a measurement of the radiation surface, and an estimate of the difference of temperature on both

sides, the loss by radiation appears to be about two thermal units per hour per square foot of surface per degree difference in temperature. The estimate in the present instance cannot be made with any degree of accuracy, and is therefore omitted in the above calculations. The experimental values of the specific heats are too low, also on account of the radiation losses. They are, however, of interest, as being one of the largest experiments on record for experimentally determining the specific heat of air at constant pressure. The experiments to determine the quantity of air delivered by the compressor are of special interest. They show that even with almost perfect valve arrangements the compressor does not deliver its full volume; yet compressors with valves as bad as they can be are often credited with delivering their full volume of air. The error of such an assumption cannot be far short of 25 per cent. or 30 per cent.

Better results as regards the mechanical efficiency, and the efficiency of the compression process have been obtained, from similar but larger compressors. Such good results cannot be expected from a compressor of this size, however perfect, as from large compressors such as those used in the Paris installation.

The Author desires to acknowledge his indebtedness to Messrs. West and Jenkins for their courtesy on several occasions in placing compressors and air-motors at his disposal for tests, and for preparing the necessary appliances.

The Paper is accompanied by six drawings and a photograph, from which the *Figs.* in the text have been prepared.

APPENDIX.

RESULT OF TESTS.

Length of trial	8 hours.
Mean speed	65 revs. per minute.
Indicated HP.—	
Right-hand steam cylinder	15·23
Left " " " "	14·14
Total	<u>29·37</u>
Low-pressure air cylinder	12·70
High " " " "	11·12
Total	<u>23·82</u>
Mechanical efficiency	81·1 per cent.
Pressure in air-receiver above atmosphere . . .	61·08 lbs. per square inch.
Height of barometer	30·16 inches.
Pressure of atmosphere	14·82 lbs. per square inch.
" in air-receiver (absolute)	75·90 " " "
Efficiency of compression process	88·8 per cent. " " "
Values of n , $P V^n$ } low-pressure cylinder . . .	1·27
= constant } high " " "	1·28
Volumetric efficiency—	
Compressor delivering air under constant pressure	91·7 per cent.
Compressor delivering air under varying pressure from 0 to 60 lbs. per sq. inch}	92·7 " " "
Volume of air actually delivered by measurement per (steam) I.H.P. per hour at atmospheric pressure	358·2 cubic feet.
Temperature of shop (dry bulb)	66·37° F.
" " " (wet bulb)	64·58° "
Dew point (according to Glaisher)	62·07° "
Percentage of moisture in air by weight	1·18 per cent.
Specific heat of moist air (calculated)	0·241
Specific heat of moist air by experiment—	
From intercooler (neglecting radiation)	0·2283
From final cooler " "	0·2297
Volume of 1 lb. of moist air at atmospheric pressure and at 73·74° F. (calculated)	18·26 cubic feet.
Weight of air (moist) delivered per stroke	0·1021 lbs.

Weight of water passed through jackets	704 lbs.
" " " intercooler . . .	1,177 "
" " " final cooler . . .	334 "
Rise of temperature of water from jackets	50·21° F.
" " " intercooler . . .	43·27° "
" " " final cooler . . .	46·90° "
Weight of air compressed during trial	2,389 lbs.
Temperature of air in shop (by thermometer)	66·37° F.
Temperature of air at beginning of compression in low-pressure cylinder (calculated from known temperature at end of compression)	73·74° "
Temperature of air on leaving low-pressure cylinder (by thermometer)	173·0° "
Temperature of air on leaving intercooler (by thermometer)	79·63° "
Temperature of air on leaving high-pressure cylinder (by thermometer)	182·0° "
Temperature of air on leaving final cooler (by thermometer)	153·46° "
Difference of temperature of air between suction and delivery (rise)	87·09° "

BALANCE SHEET OF HEAT QUANTITIES.

Heat Received.		Heat Disposed of.
Work done in air cylinders $23\cdot82 \times 33,000 \times 180$ 772	B. T. U. 183,300	B. T. U. Water-jackets, $704 \times 50\cdot21$ 35,350 Intercooler, $1,177 \times 43\cdot27$ 50,930 Final cooler, $334 \times 46\cdot90$ 15,660 Carried away by air, $2,389 \times 87\cdot09 \times 0\cdot241$ 50,140 Radiation from surfaces of water-jackets, intercoolers, cylinder-covers, and pipes, &c. (by difference) 31,220

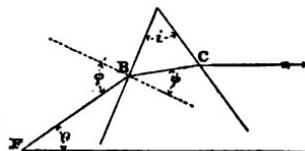
(Paper No. 2969.)

“Equiangular Prisms.”

By JOHN ARCHIBALD PURVES, B.Sc.

THE primary object in lighthouse optics is to parallelize as nearly as possible the rays emitted by the burner; but with such a luminary as a 6-wick burner in the focus, the area of flame is such as to produce a cone of divergent rays, incident upon every point of the interior of the apparatus, of an angle varying between 2° and 3° for small flames and between 5° and 6° for large burners. As it is impossible to reduce this cone of rays internally, except by increasing the diameter of the apparatus, the prisms must be constructed to reduce, as far as possible, the angle of this cone outside the apparatus, or at least to preserve it constant both inside and outside. The latter condition is satisfied by the equiangular prism, or prism of minimum deviation, a form of lens which has been introduced by Mr. Charles A. Stevenson, M. Inst. C.E. The difference in the angles of the external cone only becomes marked as the distance from the focal plane becomes great; for at the focal plane itself the difference between the conical angle of spherical and equiangular sections amounts to only $8''$ in an initial angle of cone of 4° . At 15° the angle of the external cone of the spherical refractor exceeds that of the plano refractor by $31' 14''$ and exceeds the equiangular by $43' 24''$. At 30° above the focal plane the spherical exceeds the plano by $3^\circ 28' 34''$ and the spherical exceeds the equiangular refractor by $4^\circ 17' 3''$. The advantages derived from this property are at once apparent, for the intensity of the light varies inversely as the angle of this cone. On account of this property it is possible to carry the refracting portion of the apparatus to a height impossible in the spherical section and certainly highly disadvantageous in the Fresnel or plano section. For, at a height of 40° from the focal plane, the angle subtended by the burner inside the apparatus being

Fig. 1.



4°, the cone of divergent rays in the equiangular section measures only 4° 0' 10", and in the plano section amounts to 5° 25' 50"; while it is impossible to construct a spherical section at this angle, as the outside face would become so obtuse to the ray in glass that total reflection would ensue. In the equiangular profile also coloured dispersion is reduced to a minimum. For if the ray F B, Fig. 1, is refracted to C, where it is finally refracted, then, D being the total deviation, θ the vectorial angle, ϕ and ϕ^1 the angles between the rays and normals at B, ψ and ψ^1 the angles between the rays and normals at C and i the refracting angle of the prism, $D = \psi - \psi^1 + \phi - \phi^1$ and $i = \psi^1 + \phi^1$ so $D = \psi + \phi - i$, whence—

$$\begin{aligned} \sin(D + i - \phi) &= \sin i \sqrt{\mu^2 - \sin^2 \phi} - \sin \phi \cos i; \\ \text{for } \sin(D + i - \phi) &= \sin \psi, \\ \text{and } \sin i \sqrt{\mu^2 - \sin^2 \phi} - \sin \phi \cos i &= \mu \sin \psi^1, \\ \text{or } \sin \psi &= \mu \sin \psi^1, \end{aligned}$$

which is true from the law of refraction. Now if the difference between the refractive-indices for the mean and the extreme rays of the spectrum of the light considered amounts to 0·01, this equation can take the form

$$\sin D^1 = \sin i \sqrt{\mu^2 - \sin^2 \phi} - \sin \phi \cos i,$$

where i and ϕ are regarded as constants and D^1 and μ variables; hence the coloured dispersion will now be obtained on differentiating this equation, $d D^1 = \frac{\sin i}{\cos D^1 \cos \phi^1} d \mu$. In the Fresnel section:

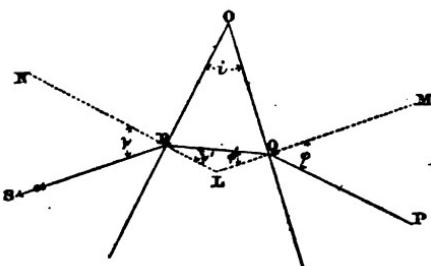
$$D^1 = D + i - \phi = i; \text{ hence } d D^1 = \frac{\tan i \times 0\cdot01}{\cos \phi^1}. \text{ In the spherical lens: } D = \theta; \phi = 0 \text{ and } \phi^1 = 0, d D^1 = \frac{\sin i \times 0\cdot01}{\cos(i + \theta)}, \text{ and in the equiangular: } \phi = \frac{D + i}{2}; D = \theta, d D^1 = \frac{2 \tan \phi \times 0\cdot01}{\mu}.$$

The following Table, derived from the above equations, shows the equiangular section is in this respect superior to either the Fresnel or the spherical. Spherical aberration is also more nearly eliminated in it than in any of the usual forms of lighthouse lenses:—

Angle above Focal Plane.	Fresnel.	Spherical.	Equiangular.
1°	1' 8"	1' 8"	1' 8"
15°	17' 46"	18' 35"	17' 22"
30°	40' 45"	52' 50"	37' 15"

With regard to the essential optical property of such prisms, let P Q R S, *Fig. 2*, be the path of a ray through a prism the apex of which is at O, and the refracting angle i . The normals at R and Q are L N and L M. If the total deviation,

Fig. 2.



D, be a minimum, $D = \psi + \phi - i$, $i = \phi^1 + \psi^1$; hence also $\frac{dD}{d\phi} = 0 = \frac{d\psi}{d\phi} + 1$, $\therefore \frac{d\psi}{d\phi} = -1$ and $\frac{d\phi^1}{d\phi} + \frac{d\psi^1}{d\phi} = 0$.

Also, since $\sin \phi = \mu \sin \phi^1$; $\therefore \cos \phi = \mu \cos \phi \frac{d\phi^1}{d\phi}$,

$$\text{and } \sin \psi = \mu \sin \psi^1; \therefore \cos \psi \frac{d\psi}{d\phi} = \mu \cos \psi^1 \frac{d\psi^1}{d\phi};$$

$$\therefore \frac{d\phi^1}{d\phi} = \frac{\cos \phi}{\mu \cos \phi^1}, \quad \frac{d\psi^1}{d\phi} = -\frac{\cos \psi}{\mu \cos \psi^1},$$

$$\text{whence } \frac{\cos \phi}{\mu \cos \phi^1} - \frac{\cos \psi}{\mu \cos \psi^1} = 0;$$

$$\therefore (1 - \sin^2 \psi^1) (1 - \mu^2 \sin^2 \phi^1) = (1 - \sin^2 \phi^1) (1 - \mu^2 \sin^2 \psi^1).$$

$$\text{whence } \sin^2 \phi^1 = \sin^2 \psi^1,$$

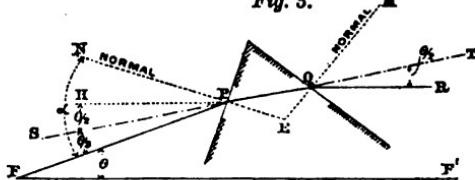
$$\text{or } \phi^1 = \psi^1 \text{ and } \therefore \phi = \psi.$$

Hence when the angle of incidence is equal to the angle of emergence, the deviation is a unique minimum.

It is possible to find an expression which will give the tangents to the outer face in terms of the vectorial angle θ . Let F F¹ be the optic axis, *Fig. 3*, F the focus, P a point on the inner face, Q a point on the outer face, and R Q the horizontal ray projected from the apparatus. Now the condition that the surfaces of the

prism at P and Q, to which P N and Q M are normals, be such as to produce equal deviation of the focal ray F P, is, that the angle F P N be equal to the angle R Q M; or, considering the ray in glass Q P to occupy the mean position, this ray produced through Q and P will be seen to bisect the angle H P F, because the ray F P is altered from its original position to the horizontal P H in its final position, and from the definition of equiangular surfaces, where each face refracts equally, it follows that the ray in glass when produced is such that P S bisects the angle F P H,

Fig. 3.



and that Q T makes an angle $\frac{\theta}{2}$ with R Q. Hence, from the law of refraction, it follows that $\frac{\sin F P N}{\sin Q P E} = \mu$; so $\frac{\sin R Q M}{\sin P Q E} = \mu$, but $P Q E = Q P E = T Q M = R Q M - \frac{\theta}{2}$.

$$\therefore \frac{\sin R Q M}{\sin \left(R Q M - \frac{\theta}{2} \right)} = \mu,$$

whence, expanding, $\mu \cot R Q M \sin \frac{\theta}{2} = \mu \cos \frac{\theta}{2} - 1$,

then $\cot R Q M = \frac{\cos \frac{\theta}{2} - \frac{1}{\mu}}{\sin \frac{\theta}{2}}$,

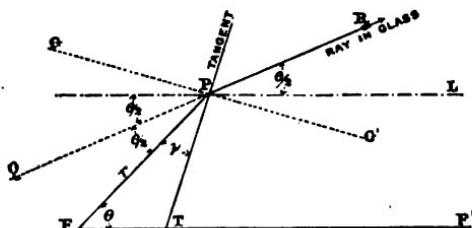
which gives the direction of normals and tangents.

With regard to the curves of the inner face, let F, Fig. 4, be the focus, and let the course of the ray be F P R. Let P T be the tangent to the surface of the lens at P. Then, as has been shown above, if P F T = θ , F P Q = $\frac{\theta}{2}$ = Q P M = R P L; by the law of

refraction $\sin F P G = \mu \sin R P G^1$, where μ = index of refraction; therefore, if ψ is the angle between the ray and the tangent,

$$\cos \psi = \mu \cos \left(\psi + \frac{\theta}{2} \right) = \mu \left(\cos \psi \cos \frac{\theta}{2} - \sin \psi \sin \frac{\theta}{2} \right).$$

Fig. 4.



But $\cos \psi = \frac{dr}{ds}$, $\sin \psi = \frac{r d\theta}{ds}$, where ds is an element of the arc of the curve in question.

$$\therefore \frac{dr}{ds} = \mu \left(\frac{dr}{ds} \cos \frac{\theta}{2} - \frac{r d\theta}{ds} \sin \frac{\theta}{2} \right),$$

$$\frac{dr}{r} = - \frac{\mu \sin \frac{\theta}{2} d\theta}{1 - \mu \cos \frac{\theta}{2}},$$

hence, integrating, $r = \frac{C}{\left(\mu \cos \frac{\theta}{2} - 1 \right)^2}$, or, if a be taken as the

focal distance from F , the above can be written

$$r = \frac{a (\mu - 1)^2}{\left(\mu \cos \frac{\theta}{2} - 1 \right)^2} \dots \dots \quad (1),$$

which is the equation to the first surface.

To derive the equation to the second or outside surface, *Fig. 5*, let F be the focus, and let the two rays $F P$ and $F P^1$ be very close, then $K P F = S Q R = \frac{\theta}{2}$, where $\theta = P F X$. Now draw $P^1 K$ parallel to $P Q$, and $P^1 m$ and $Q^1 n$ perpendicular to $P Q$. Then let $F P = r$ and $P Q = U$, and let ϕ be the angle which $F P$

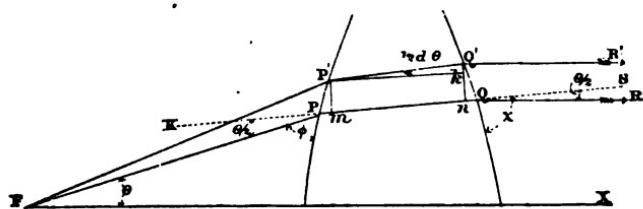
makes with the tangent to the first surface, χ the angle which PQ produced makes with the tangent to the second surface.

$$\text{Then } -dU = Pm + Qn;$$

$$\text{hence } Qn = -dU - Pm.$$

$$\begin{aligned} &= -dU - ds \cos\left(\phi + \frac{\theta}{2}\right) \\ &= -dU - dr \cos \frac{\theta}{2} + rd\theta \sin \frac{\theta}{2}. \end{aligned}$$

Fig. 5.



$$\text{Also } Q^1 n = Q^1 K + K n = Q^1 K + P^1 m,$$

$$= \frac{1}{2} d\theta U + ds \sin\left(\phi + \frac{\theta}{2}\right).$$

$$= \left(r \cos \frac{\theta}{2} + \frac{U}{2}\right) d\theta + dr \sin \frac{\theta}{2}.$$

Hence, since

$$\tan \chi = \frac{Q^1 n}{Q n},$$

$$\tan \chi = \frac{\left(r \cos \frac{\theta}{2} + \frac{U}{2}\right) d\theta + dr \sin \frac{\theta}{2}}{r \sin \frac{\theta}{2} d\theta - \cos \frac{\theta}{2} dr - dU}.$$

Again, by the law of refraction at the second surface, $\mu \cos \chi = \cos\left(\chi - \frac{\theta}{2}\right)$,

whence

$$\tan \chi = \frac{\cos \frac{\theta}{2} - \mu}{\sin \frac{\theta}{2}};$$

$$\begin{aligned} \therefore \quad & \sin \frac{\theta}{2} \left\{ \left(r \cos \frac{\theta}{2} + \frac{U}{2} \right) d\theta + \sin \frac{\theta}{2} dr \right\} \\ & + \left(\cos \frac{\theta}{2} - \mu \right) \left\{ r \sin \frac{\theta}{2} d\theta - \cos \frac{\theta}{2} dr - dU \right\} = 0; \\ \therefore \quad & \left(\mu - \cos \frac{\theta}{2} \right) \frac{du}{d\theta} + \frac{1}{2} \sin \frac{\theta}{2} U + r \sin \theta - \frac{dr}{d\theta} \cos \theta \\ & + \mu \cos \frac{\theta}{2} \frac{dr}{d\theta} - \mu r \sin \frac{\theta}{2} = 0. \end{aligned}$$

$$\begin{aligned} \therefore \quad & \frac{du}{d\theta} \left\{ U \left(\mu - \cos \frac{\theta}{2} \right) \right\} - \frac{d}{d\theta} (r \cos \theta) + \mu \frac{dr}{d\theta} \left(r \cos \frac{\theta}{2} \right) \\ & - \frac{1}{2} \mu r \sin \frac{\theta}{2} = 0; \end{aligned}$$

but $r = \frac{C}{\left(\mu \cos \frac{\theta}{2} - 1 \right)^2}$ which leads to

$$U \left(\mu - \cos \frac{\theta}{2} \right) - r \cos \theta + \mu r \cos \frac{\theta}{2} - \frac{C}{\left(\mu \cos \frac{\theta}{2} - 1 \right)^2} = K,$$

where K is an arbitrary constant. Substituting, it now appears that

$$\begin{aligned} U \left(\mu - \cos \frac{\theta}{2} \right) &= \frac{C \left(2 \cos^2 \frac{\theta}{2} - 1 \right)}{\left(\mu \cos \frac{\theta}{2} - 1 \right)^2} - \frac{\mu C \cos \frac{\theta}{2}}{\left(\mu \cos \frac{\theta}{2} - 1 \right)^2} + \frac{C}{\mu \cos \frac{\theta}{2} - 1} + K \\ &= \frac{C}{\left(\mu \cos \frac{\theta}{2} - 1 \right)^2} \left\{ 2 \cos^2 \frac{\theta}{2} - 1 - \mu \cos \frac{\theta}{2} + \mu \cos \frac{\theta}{2} - 1 \right\} + K; \end{aligned}$$

whence $U = \frac{K}{\mu - \cos \frac{\theta}{2}} - \frac{2 C \sin^2 \frac{\theta}{2}}{\left(\mu - \cos \frac{\theta}{2} \right) \left(\mu \cos \frac{\theta}{2} - 1 \right)^2}.$

By means of this last equation it would be easy to construct the second curve point by point from the first curve. It must be noticed, however, that the second curve depends on the first, since its curvature involves the constant C . It has been shown how

this constant is determined for any given problem. By properly determining the constant K of the second curve, which is possible when the angle which the lens is to subtend at the focus is given, the second curve can be drawn.

The Cartesian equations to the second surface are—

$$x = r \cos \theta + U \cos \frac{\theta}{2}; \quad y = r \sin \theta + U \sin \frac{\theta}{2};$$

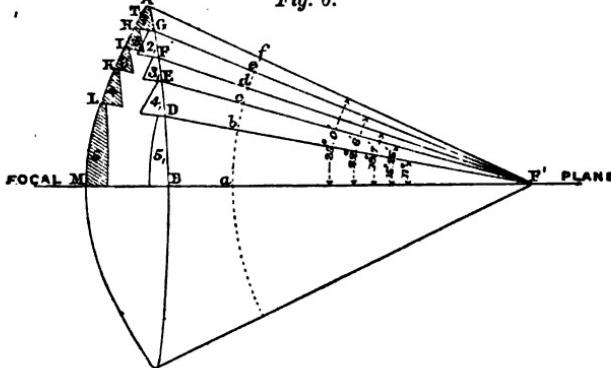
that is—

$$x = \frac{K}{\mu - \cos \frac{\theta}{2}} + \frac{C \left(\mu \cos \theta - \cos \frac{\theta}{2} \right)}{\left(\mu - \cos \frac{\theta}{2} \right) \left(\mu \cos \frac{\theta}{2} - 1 \right)^2} \quad \dots \quad (2)$$

$$\text{and } y = \frac{K \sin \frac{\theta}{2}}{\mu - \cos \frac{\theta}{2}} + \frac{2 C \sin \frac{\theta}{2}}{\left(\mu - \cos \frac{\theta}{2}\right) \left(\mu \cos \frac{\theta}{2} - 1\right)^2} \quad \dots \quad (3)$$

With regard to the practical application of these equations, supposing the lens to be constructed is of the new form shown

Fig. 6.



hatched in Fig. 6, the equiangular curve of the outer face AM can be plotted from equations (2) and (3).

In the construction of the refractor two courses can be adopted; the first is to grind the outer face of each annulus, as A H, to the nearest circular arc corresponding to this part of the true equiangular curve. To do this it would be necessary to determine from equations (2) and (3) the Cartesian co-ordinates of the points A and H and of the point T midway between A and

H. Now it is desired to find the circle which passes through these three points. This is found by taking the general equation of a circle, $x^2 + y^2 + 2gx + 2fy + C = 0$, and determining the constants g , f and C , for the co-ordinates of the centre are $(-g, -f)$, while the radius of the required circular arc is $\sqrt{g^2 + f^2 - C}$. The second method is to consider the whole length A H I K L as a circular arc which approximates most nearly to this part of the true equiangular curve. This would give a common centre for each of the prisms 1, 2, 3 and 4. This circular arc could be arrived at in a manner precisely analogous to that described, and though this method is not so accurate, it possesses the advantage of greater simplicity and ease of construction. The inside faces of the prisms in this case would not be parts of equiangular curves, but would depend upon the outer circular arc. In this case the bull's-eye would be formed of separate circular arcs approximating to the equiangular curves of the outside and inside faces.

The inside curves of the prisms A'G, H'I'', I'K'', &c., have now to be considered. The point A' being given, the equiangular curve A'G can be drawn from equation (1), and, by taking a point intermediate between A' and G and finding the Cartesian co-ordinates of the three, it is possible, as in the case of the outer face, to determine the co-ordinates of the circular arc for the portion A'G of the inner face. The point H' is fixed when the depth of arris H H' has been determined. Reconstructing equation (1) to suit the new conditions the face H'I'' can be drawn; and again by finding co-ordinates as above the centre for prism No. 2 is determined, and so on with Nos. 3, 4 and 5.

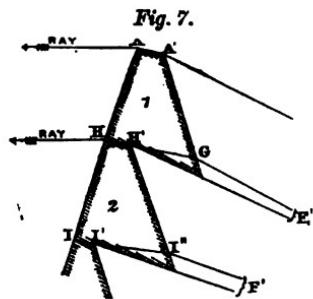
The essential feature of the inverse equiangular form of refractor consists in the inversion of the facets of the lens elements, so that they project inwards instead of outwards, and thus leave the outer face smooth. This arrangement with any other form of prism but the equiangular would entail a loss of light at each arris, which, above 15° from the focal plane, would be very considerable. With the equiangular form of prism this loss is inappreciable up to 15° , and, as will be shown, is far more than compensated for by the great gain obtained by the increase of focal length, even when the inverse refractor is carried up to a total height above and below the focal plane of 30° , thus subtending a total vertical angle of 60° .

The new form of refractor being approximately spherical possesses all the advantages of the truly spherical form, while at the same time it has none of the disadvantages arising from abnormal divergences above 20° . By using this form the same

power of light can be obtained from a smaller apparatus, thus reducing the actual cost, enabling smaller lanterns to be used, and reducing the weight of the revolving apparatus—a great consideration when quick-flashing lights are so much employed. The inverse lens has also the merit of utilizing to the fullest advantage the best part of the light. Being practically spherical in form on the outside it is impossible for the rings of this apparatus to fall inwards, hence the setting can be greatly simplified, eliminating loss of light, and reducing the weight of the apparatus.

The actual gain in power of this inverse lens remains to be shown. The profile with which it is compared is that in which the true equiangular curve is on the inside, from which the facets project outwards from the focus. This, as has been shown by Mr. Alan Brebner,¹ is 1·8 per cent. more powerful than the Fresnel section, and 15·9 per cent. than the spherical, the refractors under comparison being carried up to an angle of 31° above the focal plane.

Now in the comparison of the profile A B with A M it is seen that as the prisms of each are truly equiangular, their divergences will be altered only in respect of the greater focal distance of the prisms on A M as compared with those on A B. But in the case of those on A M there are losses of light at each arris. This loss is most easily computed when the area of the illuminated portion of a sphere subtended by the cone, the angle of which in the case before considered is 50°, is compared with the same surface of sphere minus the zones of partial darkness produced by the loss at the arrises, represented in Fig. 7 by G F' H', I" F' I', &c. Summing all these zones it will be found that the total area : reduced area :: 1·06 : 1; or, in this respect, the inverse refractor is 6 per cent. less powerful than that with which it is compared. To simplify the calculations, the areas of all the zones, $a d$, $d c$ and $c d$, Fig. 6, have each been made equal to the area of the bull's-eye, and therefore equal to one another. The powers of the rings of prisms and bulls'-eyes can now be taken simply as the squares of their focal distances. Hence—



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¹ Minutes of Proceedings Inst. C.E., vol. cxii. p. 300.

$$\frac{\text{Power of } 5}{\text{Power of } 5_1} = \frac{1,134^2}{980^2} = 33.9 \text{ per cent. more powerful.}$$

$$\frac{\text{Power of } 4}{\text{Power of } 4_1} = \frac{1,126^2}{1,009^2} = 24.5 \quad " \quad " \quad "$$

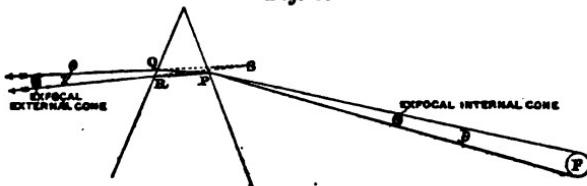
$$\frac{\text{Power of } 3}{\text{Power of } 3_1} = \frac{1,116^2}{1,038^2} = 15.5 \quad " \quad " \quad "$$

$$\frac{\text{Power of } 2}{\text{Power of } 2_1} = \frac{1,112^2}{1,069^2} = 8.2 \quad " \quad " \quad "$$

$$\frac{\text{Power of } 1}{\text{Power of } 1_1} = \frac{1}{1} = 0.0 \quad " \quad " \quad "$$

Whence, taking the average, it is found that the whole inverse apparatus is 16.4 per cent. more powerful, but with the loss at the arrises, which amounts to 6 per cent., the total gain of the inverse equiangular refractor amounts to 10.4 per cent.

Fig. 8.



It may be remarked, in conclusion, that the abnormal divergences in the spherical refractor above 20° arises from the fact that all the work of refraction is performed by the outside face. In the Fresnel it is divided between the inside and outside faces, the latter, however, refracting more than the former. The work of each face in the case of the equiangular section has been shown to be equal, and thus a divergence smaller than either the Fresnel or the spherical is produced, *Fig. 8*. Now if the inside face be made to do more than the outside, the divergent cone will be reduced, thus producing a much more intense light. In the extreme case, when the inside face does all the work, and when the outside becomes perpendicular to the optic axis, it can be shown that at 30° the angle of the divergent cone will only be $2^\circ 26' 30''$, the angle of cone inside being 5° . At 10° the angle of the external cone will have increased to $4^\circ 40' 0''$, while at the optic axis itself it amounts to $7^\circ 38' 0''$. It will be seen, therefore, that no advantage is derived by throwing all the work as far as 10° .

upon the inside face, as at this point the external and internal angles of the divergent cones are practically the same; while below this angle, if the inside face performs all the work, the external cone actually exceeds in size the internal. Above 10° the angle is seen to diminish until at 30° it is practically halved. The disadvantage of such prisms would be that a considerable loss of light is sustained at each arris, for it can be seen at once that the under face of each prism must subtend a considerable angle at the focus, and so cause much loss of light.

The Paper is accompanied by four tracings, from which the *Figs.* in the text have been prepared.

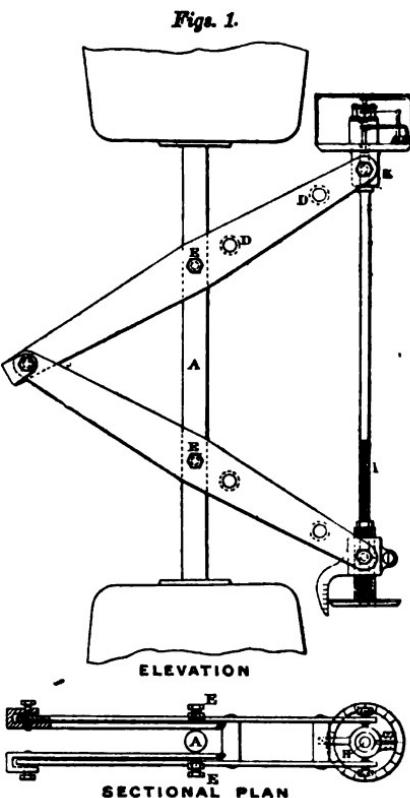
(Paper No. 2988.)

"A New Form of Extensometer."

By HERBERT ALFRED GARRATT, Assoc. M. Inst. C.E.

IN the instrument to be described in the following Paper, *Figs. 1,* two pairs of parallel steel plates are pivoted in such a way that the specimen, A, when supported between the jaws to the testing machine, can be withdrawn without disturbing the joint. They are kept parallel by fixed distance-pieces in front of the specimen. A micrometer-screw, working in a gun-metal casting, is pivoted to the end of the lower pair of plates. It has twenty-five threads to the inch, and there are two hundred divisions on the graduated disk, one division of which, therefore, gives $\frac{1}{5,000}$ inch. Owing to the multiplication of the movement by the plates, this amount corresponds to $\frac{1}{10,000}$ inch between the set screws E E. These divisions are large enough to be read easily and halved by the eye. The Author is, however, of opinion that similar instruments could be made to show $\frac{1}{30,000}$ inch without difficulty, a great

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Scale, $\frac{1}{2}$ inch = 1 foot.

deal depending on the delicacy of the mechanism at the top. By screwing the spindle, H, into or out of the main screw and then fixing it with the check-nut, the length of the instrument is approximately adjusted to suit the length of the specimen, the final adjustment for length being made by the micrometer-screw itself. At its upper end the spindle passes through a gun-metal fitting, K, too great an upward movement being prevented by a stop. To the top of the spindle is fixed a hard steel piece, and on the centre of this a round pointed pin rests, being part of the mechanism of an aneroid barometer, the steel piece taking the place of the usual vacuum box. The action of the instrument is as follows:—As the specimen stretches the spindle draws down from the aneroid, the movement of which is more than the corresponding movement at the circumference of the micrometer disk. It is the duty of the experimenter to screw up the micrometer-screw and keep the needle of the aneroid at zero, readings being taken from the disk at definite intervals. The slight oscillations of the beam of the testing-machine, which take place after setting it level at each increase of load, produce a corresponding swinging of the needle, which must be allowed to subside before taking the reading. The Author has found the instrument very convenient in use; the weight of the parts of the instrument is practically the only force acting on the joints, which are therefore in constant thrust without backlash, the spring in the plates keeping all the centres up to their work. The instrument can be used in a vertical, horizontal, or any other position, and as used by the Author will take specimens from 10 inches downwards between the set screws, and up to 1 inch in thickness and 4 inches in width.

The Paper is accompanied by a tracing from which the *Fig.* in the text has been prepared.

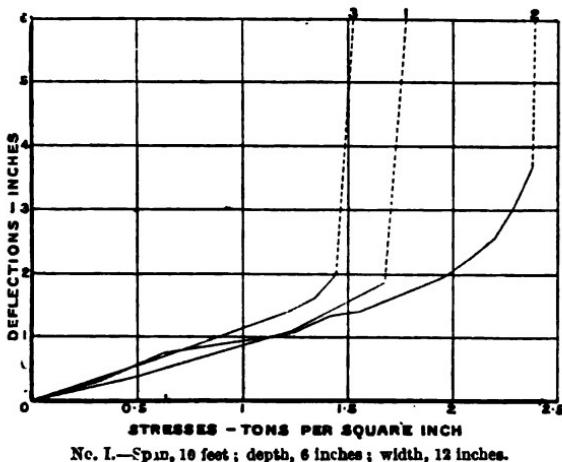
(Paper No. 2980.)

"Transverse Strength of Large Beams of Yellow-Pine Timber."

By HAROLD DUKE SMITH, Assoc. M. Inst. C.E.

TESTS to destruction of yellow-pine timber are so rare that, with the exception of those made by Mr. George Fosbery Lyster, M. Inst. C.E., and described in a Students' paper¹ by Mr. Graham Smith in 1875, the Author has been unable to find records of any made in England. In America, however, extensive tests have been made by Professor

Fig. 1.



Lanza,² and on the Continent by Professor Bauschinger³ and by Major Moritz Bock.⁴ The rarity of tests of this description is more

¹ *Engineering*, 7th May, 1875.

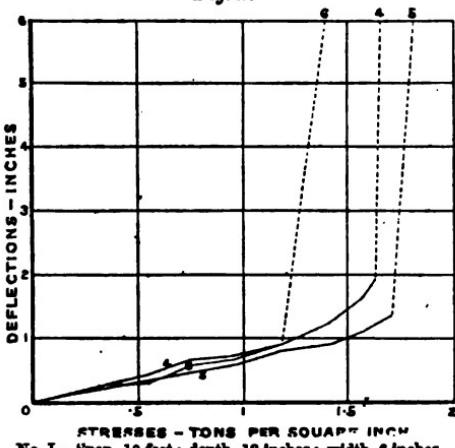
² "Applied Mechanics," New York, 1890, p. 382.

³ Mittheilungen aus dem Mechanisch-Technischen Laboratorium der k. Technischen Hochschule in Munchen, Heft 9 and 16.

⁴ Minutes of Proceedings Inst. C.E., vol. cvi. p. 356.

to be regretted, as the few that have been made on the kinds of timber used in engineering works show that the results of experiments on small samples, as quoted by the earlier authorities, are misleading, and cannot be applied to large timbers used in practice without great uncertainty.

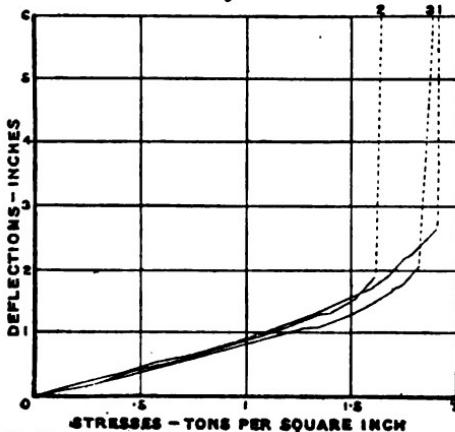
Fig. 2.



No. I.—Span, 10 feet; depth, 12 inches; width, 6 inches.

been seasoned, and, when tested, contained as most timber when actually used. The baulks were sawn, and, to clearly show the fractures, all except those measuring 12 inches by 12 inches were passed through the planing-machine.

Fig. 3.



No. II.—Span, 14 feet; depth, 12 inches; width, 12 inches.

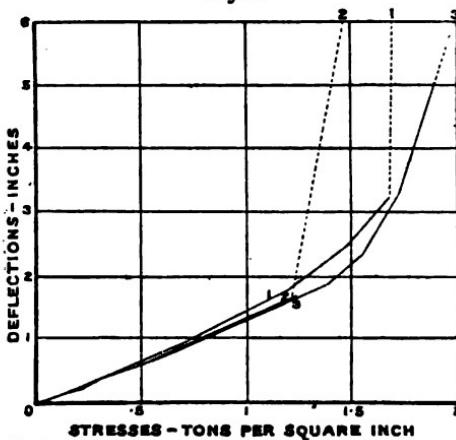
by moving the cast-iron blocks. In the centre of the beam, on a $\frac{1}{4}$ -inch wrought-iron plate, measuring 12 inches in the direction of the length of the beam, and as wide as the widest beam, rested

a large cylindrical pin, from the ends of which chains were attached to the cradle bearing the weights. While the weights were being applied, the cradle was supported on wedges, which were knocked out at intervals to allow of the deflections being measured. About 1 ton was added between each measurement at the beginning of the test; but as the deflections became greater they were measured more frequently, and finally the wedges were removed and the weights added singly. At the centre of the top of the cylindrical pin was a centre-punch hole, in which the long leg of an L-shaped scribing-tool worked. The short leg scribed the deflections on a strip of tin nailed to a 9-inch by 3-inch plank fixed to both abutments and passing over the centre of the test-piece.

SIMPLE BEAMS.

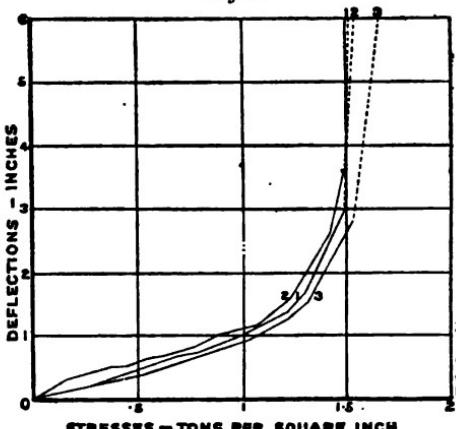
Three beams of each dimension given in the Table on the following page were tested. The results are plotted in *Figs. 1 to 5*. With the single exception of No. I. 2, which failed at a stress of 2.38 tons per square inch, none of the beams bore 2 tons per square inch. The mean breaking stress was 1.72 ton, and the minimum 1.38 ton per square inch in the case of No. I. 6. Comparing the means of each group of three tests it is seen that the breaking stress decreases as the ratio of span to depth.

Fig. 4.



No. III.—Span, 14 feet; depth, 9 inches; width, 9 inches.

Fig. 5.



No. IV.—Span, 14 feet; depth, 18 inches; width, 9 inches.

This variation is more apparent than real, and must be modified by the following considerations. Nos. I. 1-3 contain an abnor-

DIMENSIONS OF THE SIMPLE BEAMS TESTED.

Span.	Depth.	Width.
Feet.	Inches.	Inches.
10	6	12
10	12	6
14	12	12
14	9	9
14	18	9

mally strong beam. The 12-inch by 12-inch beams (Nos. II.) were the slowest, while the 18-inch by 9-inch (No. IV.) were the fastest grown timber in the group.

No.	Span Depth.	Mean "Breaking Stress."	Mean Weight per Cubic Foot.
I. 1-3	20	Tons per Sq. In. 1.90	Lbs. 37
III. ..	18.6	1.71	32
II. ..	14	1.82	41
I. 4-6	10	1.62	39
IV. ..	9.3	1.56	32

The weight per cubic foot is the weight when tested. All the timbers had been kept under the same conditions for five months before being tested, so that the weights may be compared among themselves, but as the absolute dryness was not ascertained, they are not comparable with those of other experiments. The ratio of mean breaking stress to mean weight per cubic foot is 0.048. These results, though much lower than those of the American tests, present no inconsistencies, and agree with Mr. Lyster's, which were made under about the same conditions. In nearly all cases complete fracture was preceded by a partial failure of the upper portion of the beam, clearly shown by cracks, beginning on the upper edge and running gradually downwards as the load increased, the fibres immediately on each side being crumpled outwards. Nos. I. 5, IV. 1, and IV. 2, split from the load towards the ends of the beams along lines, in No. I. 5 about 2 inches, and

in Nos. IV. 1 and IV. 2 about 5 inches and 7 inches, respectively, from the centre of the beam. In the three remaining deep beams (Nos. I. 4, and I. 6, and IV. 3) long cracks appeared in the same direction and all below the original neutral axis. Transverse fracture and longitudinal splitting were almost simultaneous, but to the eye and ear the transverse fracture seemed to begin first. The object of the tests was principally to find the breaking stress, and the deflections were not measured quite exactly, as they include the compression of the timber at the bearings and under the central plate. For this reason the moduluses of elasticity of the deeper beams, giving a large bearing stress, are somewhat too low. For the nine beams (Nos. I. 1-3, II. and III.) in which the ratio of the span to depth was more than 14, there was no appreciable compression, and as a compression of $\frac{1}{16}$ inch was easily noticeable and an error of this amount would only lower the results by about 6 per cent., the figures given are practically exact. The moduluses of elasticity, from the deflections due to a stress of 1 ton per square inch, which the *Figs.* show to be within the elastic limit, are for the nine beams :—

	Tons per Square Inch.
Maximum	472
Mean	417
Minimum	351

The following Table of the mean results of all the tests on large beams that the Author has been able to find, shows that this ratio is remarkably constant for various kinds of pine timber :—

No. of Tests Made.	Kind of Timber.	Mean Results.	Ratio of Means.		Authority.
			Tons per Square Inch. <i>f</i>	E <i>f</i> / <i>E</i>	
9	American Yellow Pine . . .	1·81 417 230			{ Tests described in this Paper.
47	" " "	3·40 786 231			Prof. Lanza.
9	Bavarian Pine	3·44 726 221			Prof. Bauschinger.
5	Pine	2·79 741 265			Maj. Moritz Bock.
21	Bavarian Spruce	3·19 718 227			Prof. Bauschinger.
11	" Larch	4·27 865 196			
5	Pitch Pine ¹	3·49 788 227			Mr. Kirkaldy.
3	Memel ¹	2·26 500 221			" "

Compressive Tests.—Three 3-inch cubes cut from the upper part of each of the 12-inch by 6-inch beams (No. I. 1-6) were crushed

¹ Minutes of Proceedings Inst. C.E., vol. liii. p. 160.

under stresses ranging between 0·89 ton and 1·33 ton per square inch. The means of the three cut from each beam ranged between 0·95 ton per square inch and 1·31 in the case of No. 2, which also gave the highest result in transverse testing. The average of all the tests is 1·12 ton per square inch. As pine timbers are stronger in tension than in compression the Author expected to find the ratio of transverse to compressive strength constant. It varies between 1·31 and 1·82 with an average of 1·55, the relation of the two values being given by the empirical formula $f = 2 \cdot 88 p_c - 1 \cdot 47$. With a much wider range Prof. Bauschinger's pine tests agree individually with the formula $f = 2 \cdot 3 p_c - 2 \cdot 37$ derived from their means, while the value of $\frac{f}{p_c}$ varies between 0·82 and 1·60 with a mean of 1·36. The following Table gives the values of this ratio for tests already quoted:—

Kind of Timber.	$\frac{f}{p_c}$	Authority.
Larch	1·43	Prof. Bauschinger.
Spruce	1·31	" "
White Pine	1·35	" "
Pitch Pine	2·06	Mr. Kirkaldy.
Memel	1·69	" "

It is worthy of notice that the gain in transverse over direct strength is less in timber than in iron, and possibly investigation of this fact may lead to some satisfactory explanation of the well-known phenomenon.

Tensile Tests.—Tensile tests were made of portions of the same beams from which the compressive test-pieces had been cut. The first test-pieces were cylindrical with enlarged ends, were turned to fit the jaws of an ordinary testing-machine, but it was found that, to prevent the cylindrical part shearing out from the enlarged ends, the test-pieces had to be reduced so much that the results were not reliable. The test-piece finally adopted was 3 inches by 3 inches in section, for a length of 1 foot in the centre, splaying out, in a length of 1 foot 3 inches, to a section of 9 inches by 6 inches at each end. These ends were enclosed in iron jaws, cast in two pieces and bolted together, and the pieces were broken in a chain-testing machine. In the case of No. I. 5, after most of one of the enlarged ends had been drawn through the neck of the casting, and the timber in it compressed to one-third its

original bulk, a wedge sheared off and the whole end drew out and prevented the completion of the test. In the other cases the ends were drawn out about 1 inch before fracture occurred, so that the jaws were not by any means too large. This difficulty in securing the samples has no doubt led to the employment of the very small sections used in tensile tests of timber the results of which are published. The results vary between 1·39 and more than 2·22 tons per square inch, with a mean of 1·75. This is the same as the transverse strength, but the ratio of transverse to the tensile strength in the same beam varies between less than 0·82 and 1·31. The ratio of tensile to compressive strength varies between 1·32 and more than 1·88, the mean being 1·56.

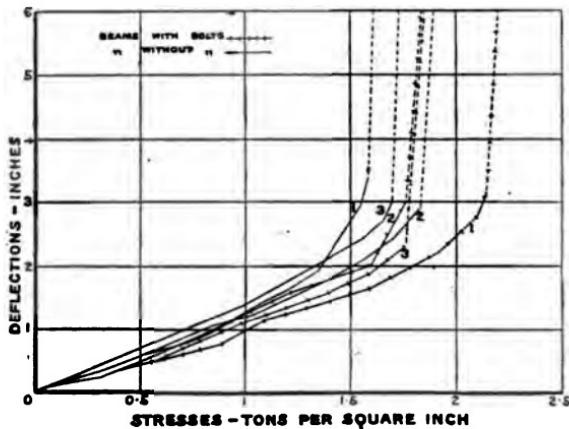
BUILT BEAMS.

Tests of built beams of large dimensions are even more rare than those of simple beams. The practice of building up a deep beam by bolting together smaller baulks upon one another is a very convenient one, and owing to the high price of large timbers it is frequently employed in temporary bridges. Much uncertainty exists, however, as to whether the bolts lead to any increase of strength. It was to decide this point that the following tests were made.

The units of which the beams were composed were 9-inch by 9-inch baulks, so that, the span being also the same, Nos. III. form part of this series. These baulks were combined in pairs and triplets, loose and bolted together, and of each combination three tests were made. The stresses have been calculated as if the baulks were placed side by side. They are therefore those which would have been produced by the same loads equally divided between all the separate baulks composing each beam. In this way the stress given is not the actual stress (which is incalculable) but is some function of it. The difference between the value of this function at breaking and the probable breaking stress is given as a percentage in the Table below. In this way the built beams may be easily and strictly compared for stiffness and strength among themselves and with the simple beams (Nos. III.). Comparing the diagrams of deflections, *Figs. 4, 6 and 7*, it is at once apparent that beams when superimposed are stiffer than when placed side by side. Under the same unit stresses three beams (Nos. VII.) are much stiffer than two (Nos. V.), and, in a less degree, two are stiffer than one. No doubt this is due to the friction between the surface of the baulks and to the distribution of the load on the

lower baulks. Bolts increase this friction and, as would be expected, produce a marked increase in the stiffness of the beam,

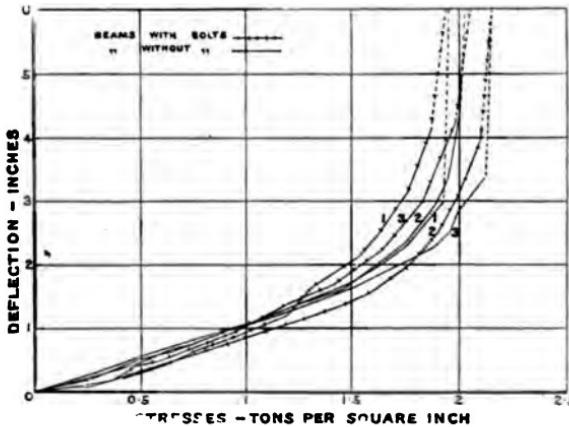
Fig. 6.



Nos. V. and VL.—Span, 14 feet; two 9-inch by 9-inch beams superimposed.

especially under lighter loads. In the bolted beams one baulk slid over the one below it, generally slowly and quietly, but

Fig. 7.



Nos. VII. and VIII.—Span, 14 feet; three 9-inch by 9-inch beams superimposed.

occasionally a sudden run would occur with much creaking and groaning.

The following Table gives the comparative strength of the different combinations:—

No. of Tests.	Description.	" Breaking Stress " Mean of Three.	Gain in Strength over the simple Beams, Nos. III.
		Tons per Sq. In.	Per Cent.
III.	9-inch × 9-inch simple beams	1·71	..
V.	Two 9-inch × 9-inch baulks superimposed	1·74	2
VI.	" " " and bolted	1·95	14
VII.	Three " 9-inch × 9-inch baulks superimposed . . .	2·05	20
VIII.	" " " and bolted . . .	2·05	20

The bolts appear to have little effect on the ultimate strength. Apparently there is no increase in No. VIII. over No. VII. When one of these beams (No. VIII.) was cut open down the centre it was found that the bolts had been bent at each joint of the baulks and pressed sideways into the timber, in some cases to the extent of $\frac{1}{8}$ inch. They must therefore have had some effect which was counteracted by other causes. Major Moritz Bock found no increase in ultimate strength derived from bolts.¹

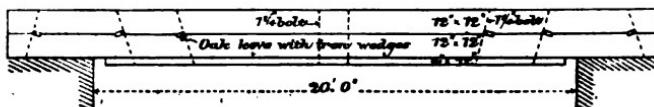
In each of the tests of three superimposed baulks No. VII., a curious phenomenon occurred which was entirely absent in the corresponding bolted beams. A little before the ultimate load was reached, compression cracks, similar to those already described in the simple beams, appeared in the upper edges of the lower baulks. It is difficult to find any explanation of this. It is difficult to suppose that the compression was greater in the lower baulks, for the friction between the surfaces would produce the reverse effect.

Much more satisfactory results were obtained from the two beams (Nos. IX.), *Figs. 8 and 9*, a favourite construction of the late I. K. Brunel, who used it in many timber bridges. The specimens tested were full-size models of one span of a large continuous beam viaduct. The loads which broke the beams were 26·21 tons and 27·79 tons. The built beams, if they had been so perfectly connected that their strength was equal to a solid beam of the same depth, would have required $\frac{4 \times 1\cdot72 t \times 1568}{20 \times 12} = 44\cdot95$ tons to break them. Their actual strength was therefore $\frac{27\cdot05 t \times 100}{44\cdot95 t} = 60$ per cent. of the solid beam. Major Moritz Bock's beams were built up in nine different ways with keys and

¹ Minutes of Proceedings Inst. C.E., vol. cvi. p. 356.

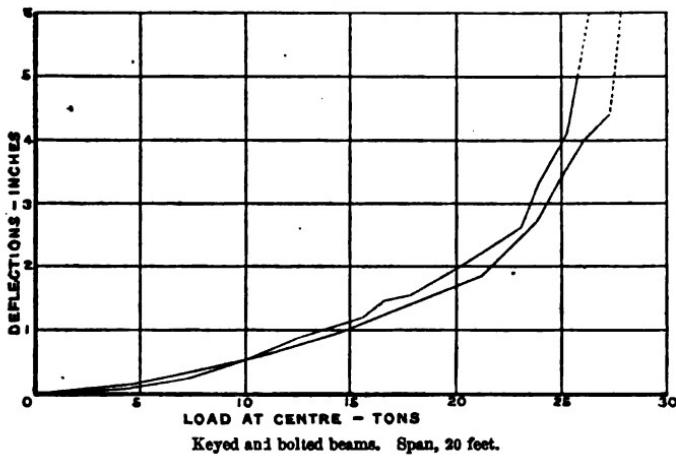
vertical bolts,¹ and the strongest of them had only 50 per cent. the strength of a solid beam.² Two others were nearly as strong as this one, the rest were hardly as strong as superimposed beams of the same dimensions. Major Bock's keys were of various forms, dimensions and material, and some, in themselves, must

Fig. 8.



have been more efficient on Brunei's pattern. The superiority of his construction is no doubt due to the inclination of the bolts. Inclined bolts not only tighten the grip on the keys when stressed, but themselves incur direct tension as well as the bending stress.

Fig. 9.



FLITCH BEAMS.

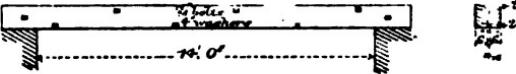
Three flitch beams, *Figs. 10* and *11*, broke with a mean load of 19.13 tons, from which each individual differed but little. It will be noticed that their deflection curves differ chiefly from those of simple beams of the same dimensions in that their breaking down is less gradual. The last measured deflections of

¹ See Plate, Wochenschrift des oesterreichischer Ingenieur- und Architekten Vereines, 1891, p. 21.

² Minutes of Proceedings Inst. C.E., vol. cvi. p. 356.

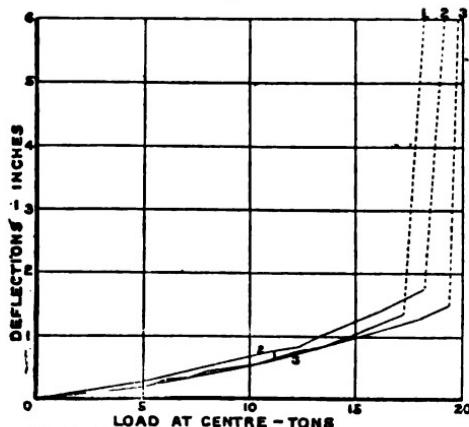
two of the flitch beams were 1·75 inch. Long before this had been reached the iron must have passed its elastic limit, and very little additional load would produce large deflections in it. This would have the effect of shortening the radius of the stress strain curve and so account for the peculiar form of the diagrams. For a flitch beam to have maximum efficiency in breaking strength, the deflection diagrams of timber and metal must be exactly similar at equal deflections,

Fig. 10.



but the practical impossibility of these conditions being fulfilled is of no importance, as beams are not built to be broken. The condition of efficiency below the elastic limit of both materials, which may be called the practical efficiency, is that the ratio of modulus of elasticity to working stress shall be the same in each. For the timber described in this Paper the working stress would be about 0·33 ton per square inch, and the modulus of elasticity was about 420. If the modulus of elasticity of the iron were 11,000 tons, it would require to be worked to $\frac{11,000}{420} \times 0\cdot33$ ton = 8·7 tons per square inch before the timber could take its fair share of the load. The timber used in these tests was therefore not suitable for combining with iron in the form of a flitch beam.

The Paper is accompanied by tabular statements of the results and by four tracings, from which the *Figs.* in the text have been prepared.

Fig. 11.

No. X.—Flitch beams. Two 12-inch by 6-inch beams, and 12-inch by $\frac{1}{4}$ -inch flitch. Span, 14 feet.

APPENDIX.

TRANSVERSE, COMPRESSIVE AND TENSILE TESTS.

No.	Span.	Depth and Width.	Weight per Cubic Foot.	Modulus of Elasticity E .	Trans- verse Strength f .	Com- pressive Strength P_c .	Tensile Strength P_t	$\frac{f}{P_c}$	$\frac{f}{P_t}$	$\frac{P_c}{P_t}$
I. 1	10	6 × 12	42	465	1·78	1·22 1·22 0·89	2·08	1·60	0·86	1·87
					Mean	1·11				
I. 2	10	6 × 12	34	421	2·38	1·33 1·27 1·33	1·80	1·82	1·81	1·87
					Mean	1·31				
I. 3	10	6 × 12	34	351	1·53	1·11 1·11 1·10	1·47	1·31	1·04	1·82
					Mean	1·11				
	Means of 3 tests			412	1·90	1·18	1·78	1·58	1·07	1·52
I. 4	10	12 × 6	29	..	1·67	0·89 1·00 0·97	1·39	1·69	1·20	1·46
					Mean	0·95				
I. 5	10	12 × 6	43	..	1·81	1·22 1·11 1·20	>2·22	1·54	<0·82	>1·88
					Mean	1·18				
I. 6	10	12 × 6	35	..	1·88	1·00 1·04 1·11	1·59	1·31	0·86	1·51
					Mean	1·05				
	Means of 3 tests			..	1·62	1·06	1·78	1·51	0·96	1·62
	Means of 6 tests			..	1·76	1·12	1·76	1·55	1·00	1·56

SIMPLE BEAMS.

No.	Span.	Depth and Width.	Weight per Cubic Foot.	Modulus of Elasticity.	Transverse Strength.
	Feet.	Inches.	Lbs.	Tons per Square Inch.	Tons per Square Inch.
II. { 1 2 3 }	14	{ 12 x 12 }	44	421	1.93
			41	436	1.65
			37	472	1.90
			Means . .	40.6	1.82
III. { 1 2 3 }	14	{ 9 x 9 }	32	368	1.69
			33	402	1.46
			32	415	1.99
			Means . .	32.8	1.71
IV. 1	14	{ 18 x 9 }	36	..	1.52
			32	..	1.54
			27	..	1.65
			Mean . .	31.6	1.57

BUILT BEAMS.

No.	Span.	Cross Section.	Breaking Weight.	Transverse Strength.
V. { 1 2 3 }	Feet. 14	{ Two 9-inch x 9-inch beams, superimposed. }	Tons.	Tons per Sq. In. 1.60 1.89 1.73
			Mean . .	1.74
VI. { 1 2 3 }	14	{ Two 9-inch x 9-inch beams, superimposed and bolted together. }	.. .. ..	2.19 1.83 1.84
			Mean . .	1.95
VII. { 1 2 3 }	14	{ Three 9-inch x 9-inch beams, superimposed. }	.. .. ..	1.96 2.03 2.17
			Mean . .	2.05
VIII. { 1 2 3 }	14	{ Three 9-inch x 9-inch beams, superimposed and bolted together. }	.. .. ..	1.93 2.16 2.05
			Mean . .	2.05
IX. { 1 2 }	20	{ I. K. Brunel's construction. }	26.31 27.79	
X. { 1 2 3 }	14	{ Flitch beam. Two 12-inch x 6-inch beams. One 12-inch x $\frac{1}{8}$ -inch wrought-iron flitch. }	18.26 19.18 19.95	
			Mean . . .	19.18

(*Paper No. 2991.*)

(*Abridged.*)

“Mineral Resources of the Argentine Republic.”

By JAMES MCKEAN ROWBOTHAM, Assoc. M. Inst. C.E.

OWING to the want of economical transport, comparatively little has been done to develop the mineral resources of the Argentine Republic. At the present time the ores are carried on mule-back for a distance of 100 miles to 300 miles to the nearest railway station. Happily this disadvantage will soon be obviated, as the Government has realized the importance of pushing on the railways, and steps have been taken to continue the Great Southern and the Western systems to the far west, the Mendoza line to San Rafael, and the Dean Funes line from Patquia to Chilecito. The most important mining provinces are Catamarca, Rioja, San Juan, Mendoza and Salta, and the National territories of Neuquen and Chubut. The minerals met with comprise gold, silver, copper, lead, mercury and iron ores, coal, limestone, petroleum, salt, nitrate, borax, sulphur and asbestos. The great variety of the mineral products was well shown by the striking collection of economic minerals shown at the Paris (1889) and the Chicago (1893) Exhibitions.

The traces of furnaces with copper and silver slags that have been found afford evidence that mining on a limited scale was carried on three hundred years ago; and the Spaniards, while in possession of the country, made numerous unsuccessful attempts to discover the mines of the Aborigines. It is very difficult to ascertain the quantity of ore mined at the present time, as much is taken over the Andes to Chile on mule-back, and no returns are made. It may, however, safely be estimated that the value of the annual mineral production of the country does not exceed £300,000. The annual exports are approximately as follows:—

Lead ore 310 tons, silver ore 370 tons, copper regulus 115 tons, bar copper 150 tons, borax 130 tons, and other minerals 250 tons.

The number of mines registered in the Republic amounts to 1,583, the chief of these being gold 526, silver 606, copper 65, coal 91, salt 76, and nitrate 64. It is probable, however, that no

more than one-quarter are worked, the operations being conducted in most cases in a primitive and wasteful manner.

The province of Rioja is the chief centre of the mining industry. In the Famatina mountains and in the district round Chilecito and Villa Argentina, mining for gold, silver, copper and lead ores has been carried on for upwards of 150 years; but latterly, owing to the fall in the value of silver and the heavy cost of transport, the mines have been almost entirely neglected. The railway that is shortly to be continued from Patquia to Chilecito will, however, open up this important mining district. In the Famatina range, gold-washing has yielded 136 grams ($4\frac{1}{4}$ ozs.) of gold to the ton; and besides quantities of gold and silver, the firm of Treloar of Villa Argentina exports 200 tons annually of copper regulus, containing 60 per cent. of metal, to England. It is sold at £60 per ton, the freight from Villa Argentina to England being £8. Refractory material of excellent quality is found in this district, and is used for the construction of smelting furnaces. Important copper mines are worked in the district of La Mejicana in the Famatina range, where Messrs. Forrest and Co. have a smelting works with the only Siemens regenerative furnace in the country. The production of these works amounts to 150 tons of copper regulus annually. Ingots from these works have been sold in London at £72 2s. 10d. per ton, the metal containing 61·79 per cent. of copper, 3·97 ozs. of gold per ton, and 262 ozs. of silver per ton.

The province of Cordoba, where lead and silver ore deposits occur about 40 miles north-west of the city of Cordoba, is well provided with railways, and should have a large mineral production. Owing, however, to revolutions, misrule, and foreign speculation, little progress has hitherto been made in the development of its mineral resources. Gold quartz yielding 3 ozs. to the ton is met with at San Ignacio. Marble of superior quality is quarried and largely used in building construction, lime made from it being used throughout the Republic.

The province of Catamarca is undoubtedly one of the most important mining centres. In the district of Andalgala extensive copper mines and works are owned by Mr. Lafone Quevedo, who employs some two hundred workpeople and keeps three thousand mules for the transport of the products. During a period of ten years, the ore mined amounted to 22,000 tons, yielding 4,000 tons of copper, the aggregate value of which was 1,590,000 dollars. The expenses were 1,195,000 dollars, and the net profit 395,000 dollars. The ore yields about 16 per cent. of copper, together with small proportions of gold and silver. The mines are situated at an altitude

of 10,000 feet above sea-level, and of 7,000 feet above the Pilciao valley where the works are situated. One of the most important ore deposits in this province is that of haematite, which was discovered by Mr. G. Romay in large quantities in a mountain range about 10 miles from the Dean Funes station of the Central Northern Railway, near the old Indian village of Albigasta. Since the revolution of 1890 nothing has been done to develop these mines. According to Mr. E. Riley's analysis, the ore contains—

	Per Cent.
Silica	2·55
Ferric oxide	52·21
Ferrous oxide	14·89
Alumina	5·40
Titanic anhydride	18·17
Manganese oxide	0·97
Magnesia	4·28
Combined water	0·93
Total	<u>99·40</u>

The mines are situated in the midst of extensive woods, and there is a river close to the spot where the erection of ironworks was begun.

In the province of San Juan, mines of gold, silver, copper, iron and coal have been worked. Owing to the want of railway transport, operations have been conducted only on a very small scale. Assays of samples give, however, satisfactory results, copper ore yielding 9 per cent. to 44 per cent. of metal, and gold quartz from the Gualilan mountains, where it occurs in abundance, yielding $1\frac{1}{2}$ oz. of gold and a small proportion of silver per ton as the average of thirty-two tests. In 1867 an English company was formed with a capital of £50,000 for working mine concessions in this province. Owing to mismanagement, however, the capital was all spent on unsuitable machinery and on office expenses before mining was fairly started.

In the province of Mendoza, extensive beds of bituminous coal have been found in the department of San Rafael. Although some of the coal is well adapted for boiler purposes and for gas-making, as well as for the manufacture of coke of fair quality, it has hitherto been but little used, except locally. When the railway from Mendoza to San Rafael, for which a concession has been granted, is constructed, this coal will no doubt compete with the imported material for use on the railways in the far west. Petroleum has been found at a depth of 600 feet, and a cast-iron pipe-line, 22 miles in length, has been laid to the nearest railway station, in order to enable the petroleum to be used as locomotive

fuel. Gold is said to occur near Uspallata, and ores of copper and silver have been found at various places, but the deposits have not yet been worked.

In the province of Salta, mining for silver and lead ore is being extensively and profitably carried on. Galena is very plentiful in all the ravines on the slopes of the Andes. The Esperanza mine, owned by Mr. A. C. Rosca, yields ore averaging 157 ounces of silver per ton. The ore is taken to two works at Chorillos. At the Salteno drift, the ore yields 70 ounces of silver per ton, and 70 per cent. of lead; and from another lode, about a mile south of the Esperanza mine, ore is obtained containing 20 per cent. of copper, and 240 ozs. of silver per ton. In this district some twenty veins of antimony ore, as yet unworked, occur in the vicinity of thermal springs.

In the territory of Neuquen, coal has been found near Chos-Malal, the town to which the Buenos Ayres Southern Railway Company is about to extend its line. The coal, which occurs in a bed 7 feet to 9 feet in thickness near the surface, is similar in quality to that of the Mendoza seam. An assay of the coal by Dr. Kyle gave the following results:

Water.	Carbon.	Volatile Matter.	Ash.
0·84	40·38	54·05	4·00

Other samples taken from the outcrop have given between 48 per cent. and 60 per cent. of carbon and a calorific power of 54·05. Copper ore, nickel ore, marble, petroleum, and auriferous sands also occur in this territory.

Great attention has recently been paid to the south of the republic, the territories of Chubut, Santa Cruz, and Tierra del Fuego, where gold, chiefly alluvial, is found in abundance. The Chubut colony, which up to a recent date was occupied almost exclusively for agricultural purposes by Welsh settlers and their descendants, has, during the last two years, become a centre of gold-digging activity. Numerous mining concessions have been granted; samples, not always trustworthy, of quartz and sand rich in gold have been sent to Buenos Ayres, and several companies have begun operations on a large scale. No returns are, however, yet available. With appliances of the most primitive character, the yield of alluvial gold has been about $\frac{1}{2}$ oz. of gold per ton of sand.

From the particulars given in this Paper, it may be inferred that the Argentine Republic possesses vast stores of mineral wealth that cannot long be allowed to remain neglected.

OBITUARY.

JOHN BENNETT was born on the 12th December, 1823, at Fagra, near Kirkcudbright, N.B. His career as an engineer commenced in 1843 in Liverpool, where he served his time in the workshops and drawing office of Messrs. Bury, Curtis and Kennedy. He was then for two years with Messrs. McConochie and Cland, consulting engineers, of the same city, and subsequently spent a short period in the works of the Great Western Railway at Swindon.

In 1850 Mr. Bennett obtained employment under the Government of the Straits Settlements, and for three years was in charge, under Mr. J. T. Thomson, of the construction of the Horsburgh Lighthouse on the Pedra Branca Rocks at the entrance to the China Sea, 10 miles from the nearest land and 40 miles from food supplies. The lighthouse was built entirely by convict labour, chiefly Chinese and Malayan, on a bare rock hardly raised above sea-level, and Mr. Bennett himself fixed the revolving light. On the completion of the work, he was favourably reported to Government by Mr. Thomson. In 1854 he entered the Public Works Department of the Government of India, in which service he rose through the various grades to the rank of Acting Superintending Engineer. From 1854 to 1863 he was stationed at Singapore and superintended the building of the Rabbit and Coney Lighthouse, also at the entrance to the China Sea, a heavy isolated work. He likewise prepared the stones for the Alguada Reef Lighthouse, off Cape Negrais, on the east coast of the Bay of Bengal, cutting them at Pulo Obin in the Malay Peninsula; and carried out St. Andrew's Church (now the Cathedral), Singapore—to which he himself fixed the lightning conductor—and various public buildings and fortifications. In the execution of these works he had charge of large bodies of convicts, whom he managed with great skill and tact.

In 1864 Mr. Bennett was transferred to Penang, on the coast of the Malay Peninsula, where he carried out the works in connection with forming the new settlement. In 1867 he returned to Singapore and, in addition to his engineering duties, acted as Secretary to Government in the Public Works Department and as Superintendent of Convicts. In the same year the Straits Settlements

were placed under the administration of the Secretary of State for the Colonies, and Mr. Bennett was transferred to Burma as Executive Engineer of the Myanong division and stationed at Rangoon and Henzada, his chief work there being the reclaiming of the Rice lands (a district 90 miles by 30 miles) from the overflow of the River Irawadi, by forming an embankment along it for over 90 miles. On this work several thousand native workmen were engaged. He was invested with the powers of a subordinate magistrate within the limit of the embankment division and had charge of the Government treasury, which was kept at his house under a native guard, no other European officer being stationed at Henzada. In 1868 Mr. Bennett carried out the construction of three screw-pile lighthouses at the entrances to the Irawadi River. In the following year he was transferred from Burma to Port Blair in the Andaman Islands, where he had sole charge of all public works, both in those islands and in the Nicobar Islands, building stone barracks, making roads, forming sea embankments and erecting a church on Ross Island. During that appointment he was acting magistrate and had charge of the convict establishment.

In 1873 Mr. Bennett was transferred from Port Blair to the North-West Provinces of India as Executive Engineer and was stationed successively at Allahabad, Meerut, Cawnpore, Benares, and Calpi. In the Allahabad district he carried out several viaducts, bridges, irrigation works, a large opium factory, the Thornhill Mayne Memorial, the Government Press and the Muir College; had charge of the Grand Trunk Road for 200 miles between Benares and Cawnpore; and thoroughly renovated Government House for the reception of the Prince of Wales. He was also engaged on famine relief works, in connection with which his services were specially referred to by Government. In 1877 he was promoted to Superintending Engineer of the North-Western Provinces, which responsible position he held until his retirement in 1879.

During his whole career Mr. Bennett was greatly liked and respected, from his superiors to his lowest workmen, his manner being quiet and unassuming, yet firm, and his temper even. To those qualities, and to his ability as an engineer, may be attributed his success with native workmen. Mr. Bennett died at Dartington, Totnes, South Devon, on the 21st September, 1896. He was elected a Member on the 4th March, 1873.

BENJAMIN SHAW BRUNDELL, born on the 5th September, 1825, at Gillingham, Norfolk, commenced work at the age of fifteen with a firm of land surveyors at Colchester. Three years later he was articled to Messrs. Sherrard and Hall, of Westminster, under whom he was engaged in making surveys for the London and York Railway, afterwards known as the Great Northern. In the course of that work he records that he received a horsewhipping at the hands of the then Lord Galway, who, like many landowners at that time, was furious at the idea of a railway passing near his property. Thus began an unbroken connection of fifty years with the Great Northern Railway, to which Mr. Brundell always referred with great pride and satisfaction. He was about twenty years of age when, on the recommendation of Messrs. Sherrard and Hall, he was engaged by Mr. (afterwards Sir William) Cubitt,¹ Past-President, and was placed on the staff of Mr. Henry Carr,² who was then Resident Engineer on the Doncaster section of the line. He subsequently followed Mr. Carr to Peterborough and later to Tuxford, where he had charge of the works from Askham to Newark.

In 1857 Mr. Brundell settled in Doncaster and commenced to practise on his own account, in association with his brother-in-law, the late Mr. Tom Penrice, who, however, after some months accepted an appointment in London. One of the first works which Mr. Brundell carried out was the construction of a short railway from Sandy to Potton, about 4 miles in length, on the Bedfordshire estate of Captain William Peel. In 1864 he was appointed Engineer to the Don Drainage Commission, and in the same year he made the working survey of the Doncaster and Gainsborough Railway.

It was in 1867 that Mr. Brundell was first consulted by the Doncaster Corporation as to a sewerage scheme for that town. He suggested a reversal of the sewers in order that the discharge might take place at one point, and Mr. (now Sir Robert) Rawlinson, Past-President, having reported in favour of the proposal, Mr. Brundell was instructed to carry out the works. He then recommended the erection of a pumping-station and the pumping of the sewage to Sandall, where the Corporation possessed suitable land. That scheme, being also approved by Mr. Rawlinson, was carried out, and by 1872 the Doncaster irrigation farm at Sandall, which has since served as a model for many others, was in working order.

¹ Minutes of Proceedings Inst. C.E., vol. xxi. p. 554.

² *Ibid.*, vol. xciv. p. 364.

Mr. Brundell also acted as Engineer to the Doncaster Waterworks, which were completed in 1880 and were under his charge for six years, when they were handed over to the Borough Surveyor. While engaged on that undertaking he was responsible for the new Don drainage works, in addition to his ordinary practice, a task which must have severely taxed his energy. He was frequently consulted by other towns requiring modern systems of sewage disposal and water-supply, and carried out works at Wigan and Sleaford.

Mr. Brundell died at his residence, Christ Church House, Doncaster, on the 8th April, 1897. He was a man of cultivated tastes, refined perceptions and intelligent judgment—eminently practical and painstaking to a degree. Although burdened with a full share of the cares and worries of professional life, he was ever ready to help those in need and to bear a prominent part in local undertakings. Mr. Brundell was elected a Member on the 4th May, 1869.

BEN JAMES FISHER, born in Gloucester on the 7th February, 1838, was the son of Mr. B. Fisher, a merchant of that city. He was not fifteen when, in November, 1852, he was articled for five years to Mr. William Eassie, of Gloucester, an engineer and contractor, under whom he was engaged on what is now the South Wales system of the Great Western Railway. In 1858 he was transferred to the Engineer's office at Paddington, where he remained until 1870, when he was appointed District Engineer at Bishopstoke to the London and South Western Railway. In the following year he was transferred to the Western District at Exeter, with charge of the line west of Basingstoke, and that post he held until his death.

Among the works carried out since 1871 for which Mr. Fisher was responsible, may be mentioned the doubling of the line from Exeter to Crediton, the Sidmouth and Ilfracombe branches, the extension from Bideford to Torrington, the Plymouth extension, and the Holsworthy and Wadebridge branches. His duties brought him in contact with a large number of people, among whom he made several friends by his genial manner and kind disposition. He was a valued servant of the Company and was greatly appreciated by the Directors.

Mr. Fisher died at his residence, Hill's Court, Exeter, on the 22nd January, 1897. He was elected an Associate on the 1st February, 1876, and was transferred to the class of Members on the 14th May, 1878.

HENRY CHARLES FORDE, fifth son of the late Mr. Thomas Arthur Forde, barrister-at-law, of Seaford, co. Down, was born on the 15th April, 1827. After being educated privately at home and at school in Brussels, he was entered for three years at the College for Civil Engineers at Putney. Subsequently he served under Mr. Charles Vignoles,¹ Past President, on the survey and laying out of the Limerick and Waterford Railway. In 1846 he was appointed by the Commissioners of Public Works in Ireland an assistant engineer on the River Shannon works, which were carried out to deepen the bed of the river in order to improve the navigation from Limerick to the head of Lough Allen Canal, and at the same time to lower the flood level in order to drain the low-lying land in the neighbourhood of the river. During the great famine of that year he was also employed on various public works in Sligo, and in 1849 he was appointed Resident Engineer on the Lough Lannagh arterial drainage works at Castlebar, co. Mayo.

In March, 1852, Mr. Forde joined his former chief on the River Shannon works, Mr. Lionel Gisborne,² in a visit to South America to examine the Isthmus of Darien, with the object of cutting a ship canal from Port Escoses on the Atlantic to St. Miguel Harbour on the Pacific. This and a second expedition in the following year were carried out in the face of much native opposition. In 1854 Mr. Forde and Mr. Gisborne entered into partnership and soon became known as pioneers of submarine telegraphy. Concessions having been obtained for submarine cables from the Dardanelles to Egypt and down the Red Sea, for a line from Singapore to Batavia, and for cables from Java to Australasia, the first Eastern Telegraph Company and the Red Sea and India Telegraph Company were formed in 1857, with Messrs. Gisborne and Forde as engineers. Two years later they acted for the Government as Engineers to the Malta-Alexandria Telegraph, the successful laying of which was carried out under the supervision of Mr. Forde and was described in a Paper he contributed to the Institution in 1862.³

On the death of Mr. Gisborne in 1861, Mr. Forde entered into a partnership with Mr. Fleeming Jenkin,⁴ which lasted seven years. He was subsequently associated with Sir Charles Bright,⁵ with Mr. Latimer Clark, with Mr. Charles Hockin and with Mr.

¹ Minutes of Proceedings Inst. C.E., vol. xlili. p. 306.

² *Ibid.*, vol. xxi. p. 586.

³ *Ibid.*, vol. xxi. p. 493.

⁴ *Ibid.*, vol. lxxxii. p. 365.

⁵ *Ibid.*, vol. xciii. p. 479.

Herbert Taylor. The firm of Clarke, Forde and Taylor may be said to be largely responsible for the carrying out of a great proportion of the cable extensions throughout the world since 1869, at which date submarine telegraphy became possible as a commercial investment. After the present Eastern Telegraph Company was formed, triplicate cables were laid from Suez to Aden and Bombay, and duplicate cables between Madras and Penang, Singapore and Batavia, several of them under the personal superintendence of Mr. Forde. As engineers to the respective submarine telegraph companies, Messrs. Clark, Forde and Taylor laid down cables between Singapore and Nagasaki; England, Gibraltar, Malta and the Levant; Durban and Delagoa Bay (nearly 4000 miles) during the Zulu War; five Atlantic cables, including that from Brest to Newfoundland in 1869 (2,584 nautical miles); and the first South Atlantic cable, from Pernambuco to St. Louis in Senegal. In 1894 Mr. Forde superintended the laying of the cable from Singapore to Labuan (Borneo) and Hong Kong, a distance of 1,972 nautical miles.

Mr. Forde died at West Hill, Epsom, the residence of his cousin, Major Forde, on the 21st February, 1897. Of his ability as an engineer some impression may be conveyed by this notice. As a man he was straightforward and genial, qualities which gained for him many friends. He married in 1855 Catherine Eleanor, eldest daughter of the late Rev. R. Ferrier Jex-Blake, Rector of Great Dunham, Norfolk. Mr. Forde was elected an Associate on the 3rd February, 1857, and was transferred to the class of Members on the 11th February, 1862.

EDWARD GOTTO, born in 1822, commenced his professional career as a pupil of the late Mr. Edward Jones, of Bloomsbury, engineer and architect. He was afterwards employed on the drainage of Sandgate, and from 1842 to 1848 was in business on his own account, engaged on Parliamentary surveys for railways and other works, and at the same time holding the post of Surveyor to the Corporation of Dover. In 1848 Mr. Gotto was appointed an Assistant Engineer to the Metropolitan Commissioners of Sewers, and for three years had charge of the sewers on the north side of the Thames from Pimlico to Stoke Newington, with the exception of those within the City of London.

In 1852 Mr. Gotto took an office in Great George Street and began to practise on his own account. Work soon came to

him, and among the undertakings on which he was engaged during the next ten years may be mentioned the drainage of Chatham, Romford and Cowes, the water-supply of the last-named town, and the estimates for the main-drainage works of the Metropolis. In 1860 he entered into partnership with Mr. Frederick Beesley, an association which lasted for thirty years. The principal works carried out by the firm of Gotto and Beesley during that period were the drainage of Rio de Janeiro, Seaford, Trowbridge, Evesham, Huyton and Roby, Redditch, Brentford and Cheshunt; and the drainage and water-supply of Campos (Brazil), Oswestry, Leominster and Cinderford.

On the expiration of the partnership in 1890, Mr. Gotto assumed the position of General Manager of the Rio de Janeiro City Improvements Company, Limited, which post he held until his death at Albany Road, St. Leonards-on-Sea, on the 27th February, 1897, at the age of seventy-five. Mr. Gotto resided at the Logs, Hampstead, and was a Justice of the Peace for Middlesex. He was elected an Associate on the 13th January, 1863, and was transferred to the class of Members on the 13th December, 1870.

WILLIAM WILSON HULSE, born at Amber, Derbyshire, on the 19th June, 1821, was the second son of the late Mr. Joseph Hulse, cotton-spinner, and it was at the mechanics' shop in connection with his father's mill that he and his cousin, Joseph (afterwards Sir Joseph) Whitworth,¹ first obtained a knowledge of engineering work. After being educated at King's College, London, he was apprenticed at an early age to his cousin, who had established the Whitworth works in Chorlton Street, Manchester. He remained connected with the firm for twenty-two years, ultimately becoming managing partner with Sir Joseph Whitworth. During that period he devoted special attention to the design of machine tools and to the improvements in ordnance and small arms with which the name of Whitworth became identified, and it was he who initiated the hollow frame now universally adopted in the manufacture of machine tools.

When in 1864 the firm of Joseph Whitworth and Co. was converted into a limited company, Mr. Hulse commenced to practise on his own account as a consulting engineer in Manchester, and gained considerable reputation in that capacity. On the retire-

¹ Minutes of Proceedings Inst. C.E., vol. xci. p. 429.

ment of his brother, Mr. J. S. Hulse, from business in 1881, he took over the Ordsal Works, Manchester, and under the style of Hulse and Co., re-designed and brought up to date the machine tools for which he became so well known. He also introduced many improvements, some of which were referred to in his Paper¹ read before the Institution in May, 1886, for which he was awarded a Watt medal and a Telford premium. On the occasion of the reading and discussion of that communication, Sir Frederick Bramwell, who was then President, said that so thoroughly had the Author kept himself in the background that, had it not been for Mr. Hulse's great reputation, no one who had listened to his Paper could have gathered that he was a tool-maker and was commercially interested.²

Mr. Hulse died at his residence, The Grove, Withington, near Manchester, on the 20th March, 1897, in the seventy-sixth year of his age. In addition to his immediate work he acted as one of the British judges at the Philadelphia Exhibition of 1876 and at other exhibitions. He was elected a Member on the 21st May, 1867.

HENRY GEORGE CLOPPER KETCHUM, whose name will remain associated with the important engineering undertaking of the Chignecto Ship Railway, was born at Fredericton, New Brunswick, on the 26th February, 1839, and was educated at the Collegiate Grammar School in that town. Early in 1854 he entered King's College University, New Brunswick, where he studied engineering under Mr. Thomas McMahon Cregan, and obtained the first diploma for civil engineering granted by that University. He then passed the Government examination for deputy land surveyors, but failing to find employment in that branch of the service, he acted for a time as a telegraph operator. In August, 1856, he became an assistant to Mr. Alexander Luders Light, who was then engaged in carrying out, for the Government of New Brunswick, a line of railway from St. John on the Bay of Fundy to Shediac on the Gulf of St. Lawrence. He served under Mr. Light four years, at first as a draughtsman, and then as an assistant engineer on this line, which was at that time called the European and North American Railway but is now known as the Intercolonial Railway of Canada. Mr. Ketchum was thus, at the outset of his career, associated with an engineering enterprise in

¹ Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 120.

² *Ibid.*, vol. lxxxvi. p. 148.

the neighbourhood of the Isthmus of Chignecto, which was destined to be the scene of the most important work of his life.

In August, 1860, Mr. Ketchum proceeded to Brazil on the engineering staff of the contractors for the São Paulo Railway. He was in charge of some of the heaviest works on that line, including the Mogi viaduct of twelve spans, 180 feet high, which was constructed of iron columns on granite piers and was erected in the short space of seven months. On returning to New Brunswick in 1865 he was appointed resident engineer on the construction of the line from Moncton to Amherst, now part of the Intercolonial system, which work again brought him to the Isthmus of Chignecto. Not long after, the International Contract Company, which was responsible for the line, failed, and the Company's interest in the contract was taken over by Messrs. Clark, Punchard and Co., for whom Mr. Ketchum undertook at his own responsibility, and successfully carried out, the completion of the works as far as Dorchester. This undertaking accomplished, he began to practise on his own account in April, 1868. In the following year he was appointed chief engineer on the construction of the New Brunswick Railway from Fredericton to Edmundston, 170 miles, on which he was engaged for some years. He also acted as engineer on a section of the Quebec and New Brunswick Railway.

It was about this time that Mr. Ketchum first practically turned his attention to the great enterprise with which the last twenty years of his life were connected. In April and May, 1875, letters from him appeared in the *Daily Telegraph* of St. John, proposing a ship railway across the Isthmus of Chignecto between the Bay of Fundy and the Gulf of St. Lawrence, with railway and steam communication to Prince Edward Island and graving docks at Baie Verte, in connection therewith. This bold suggestion arrested all further idea of a canal, which had long been under discussion, but for six years no attempt was made to solve the problem of transit across the Isthmus. At length, in 1881, Mr. Ketchum carried out, at his own expense, a survey and location for a ship railway, and submitted a proposal to the Hon. Sir Charles Tupper, then Minister of Railways and Canals, offering to form a company to carry out the work, provided the Government would subsidize the undertaking, for about one-third the cost of a canal.¹ This proposal was accepted by the Government, approved

¹ See "The Cost, Feasibility and Advantage of a Ship Railway across the Isthmus of Chignecto," by H. G. C. Ketchum, Inst. C.E. Tracts 8vo., vol. 340; and "The Chignecto Ship Railway—the Substitute for the Baie Verte Canal," by H. G. C. Ketchum, Trans. Canadian Soc. Civil Engineers, vol. v. p. 329.

by Parliament, and a company, of which Mr. Ketchum was a director, was incorporated to carry out the project.

After various unsuccessful attempts had been made to induce contractors to undertake this novel and difficult work, and to find the money, Mr. John G. Meiggs, on the report of Sir Benjamin Baker, Past President, undertook the contract and a company was formed in London to carry it out. Plans were prepared and submitted—by Sir Benjamin Baker and Mr. Ketchum personally in Ottawa—to the Chief Engineer of the Department of Railways and Canals, and, after much detailed consideration, formal approval was given by the Governor-General in Council in May, 1888.¹ The works were commenced in the following October, under the superintendence of Mr. Ketchum and Sir Benjamin Baker, and were prosecuted vigorously until July, 1891, when, owing to financial reasons, they were unfortunately stopped. At that time three-fourths of the work was done—including the hydraulic lifts for raising ships of 2,000 tons gross weight a height of 40 feet, and the cradles for carrying and locomotives for hauling the ships—and it was said that but one summer season was required to finish the ship-railway and docks fit for opening to the public.² A complete description of the works by Sir Benjamin Baker has appeared in the *Nineteenth Century*,³ from which the following brief particulars are taken. The ship-railway is 17 miles long in a straight line from Fort Lawrence on the Bay of Fundy to Tidnish on the Gulf of St. Lawrence, with a dock at each end. The method of transport intended to be adopted is as follows:—A vessel coming up the Bay of Fundy on the flood tide would pass into the dock and wait its turn to be lifted. Keel and bilge blocks having been arranged on a cradle, the cradle and gridiron would be lowered by hydraulic rams into the water and the vessel hauled over it by capstans and winches in the usual way. The gridiron would then be slowly raised until the vessel rested on the keel-blocks throughout the whole length, after which the sliding bilge-blocks would be pulled tight against the ship's bilge by chains attached to the blocks and carried up to the quay on either side. Lifting, by hydraulic rams and presses, would then proceed until the rails on the gridiron attained the same level as those on the main line; the ship and cradle would then be hauled on to the railway by powerful hydraulic winches and transported by locomotives across the isthmus to the hydraulic lift

¹ Trans. Canadian Soc. Civil Engineers, vol. v. p. 332.

² *Ibid.*, p. 334.

³ *Ibid.*, p. 335, and the *Nineteenth Century*, March, 1891.

at the Tidnish end, where the converse operations would be effected to enable the vessel to resume her ocean voyage. Messrs. Easton and Anderson constructed the lifts and Messrs. Handyside and Co. the cradles.

While still fighting against adverse circumstances and—the financial difficulties having been overcome—seeking an extension of time from the Canadian Government to complete the work which had occupied so many years of his life, Mr. Ketchum, who had been in indifferent health for some months, died suddenly at Amherst, Nova Scotia, on the 8th September, 1896. His enthusiasm and confidence in the ultimate completion and success of this great undertaking never wavered. With persistent, earnest effort he devoted himself for fifteen years to the promotion of the enterprise with which his name is identified, and, although baffled when the work was within sight of completion, he never lost hope and was ready to stake all in support of his opinions. Some months before his death he had selected the spot, on the site of the great work of his life, where he now rests.

Mr. Ketchum was elected an Associate on the 1st May, 1866, and was transferred to the class of Members on the 30th April, 1878.

DAVID KIRKALDY was born at Mayfield, near Dundee, on the 4th April, 1820. As a boy his health was very precarious, and the nervous and highly sensitive disposition which this engendered remained a characteristic throughout life. He was educated under Dr. Low of Dundee, and at Merchiston Castle, Edinburgh, where he studied for some years, attending lectures also at the University. An interesting recollection was his discovery that his bedroom in the Castle had been the study of Napier, the celebrated mathematician and author of the system of logarithms. Kirkaldy had already developed a taste for experimenting (in those days it took the shape of chemistry) and was devoting a Saturday afternoon to laboratory work. Happening to burst a retort, or some vessel, and splashing the wall, he attempted to dry it, but in doing so removed the distemper, when he found traces of geometric figures and diagrams on the wall. The principal, Dr. Chalmers, had the walls carefully cleaned down, bringing to light many interesting souvenirs of the mathematician's work.

On leaving Merchiston, Kirkaldy returned to Dundee and worked in the office of his father, a merchant and shipper. But mercantile work was sorely against his inclinations, although, to please his

father, he honestly tried to like it. His career might have been confined to this sphere, but owing to the kindness and foresight of Mr. Erskine, of Linlathen, he was entered in 1843 as an apprentice in the works of Mr. Robert Napier,¹ the shipbuilder, at Glasgow. All through life Kirkaldy remembered this act of kindness and spoke often of it. He gave himself up entirely to engineering and, besides working all day, devoted his evenings to special studies. His capacity for work, and his faculty for devoting himself to minute details, were prominently shown at this time, and before he had completed his apprenticeship he was promoted to responsible positions in his employer's works. Having a strong artistic bent, he took up drawing with keenness and, striking out a new line, astonished engineers with his productions of highly finished and artistically coloured drawings. He was awarded a medal for a series of five drawings at the Paris Exhibition in 1855, and in 1861 his beautiful coloured drawing of the steamship "Persia" was exhibited at the Royal Academy, the only instance, it is said, in which this honour has been accorded to an engineering drawing.

The strong bent of his mind for experimental work and research took the direction, while at Mr. Napier's, of investigating the best lines and forms of ships, and systematically recording the details of each ship and set of engines during construction and of their performances during trial-trips. His earnestness and enthusiasm in this pursuit brought him into much trouble. The foremen were mostly prejudiced, while others higher in authority were jealous of his advanced ideas and perhaps resented many improvements in details which he gradually introduced. The prejudice and undercurrent of feeling at last became so bitter that his employer was approached, and even induced to dispense with the trial-trip performances, to the regret of Kirkaldy, who saw plainly that the time was coming when shipbuilders would require to estimate for and to build and engine ships to rigorously defined requirements as to capacity, speed, draught, and, not least, low consumption of fuel. It had been his earnest desire to serve his master to the utmost of his power in this direction, by faithfully collecting in good time a vast accumulation of data and experience upon which to act in future, and with the confident hope that thereby the firm would be able to more than hold its own against rival competition. The evenings of more than ten years had been devoted, without fee or reward, to the collection and classification

¹ Minutes of Proceedings Inst. C.E., vol. xlvi. p. 246.

of data and details in an accessible form of all the vessels and engines constructed at the works.

Although disheartened at this treatment, his energy soon found vent in another channel, which eventually was to prove his life-work and bring him wide reputation. In 1858 Napier received orders for some high-pressure boilers and marine machinery in which lightness combined with strength was an important factor. It was proposed to use homogeneous metal for the one, and puddled steel for the other, instead of wrought-iron as ordinarily employed. In connection with this order, Kirkaldy was selected by the firm to devise apparatus for, and to make experiments to ascertain the relative merits of, those at that time new materials. The original intention was only to make a few experiments upon each variety, but the investigation proved so interesting in itself, and so likely to lead to important results, that he was induced to extend the experiments considerably; and he obtained the sanction of Messrs. Napier for doing so as opportunity offered. For the purpose of carrying out these operations he designed and erected a testing machine; the testing was commenced by him on the 13th April, 1858, and terminated on the 18th September, 1861. He entered into the work with characteristic earnestness, and during that period carried out a large number of experiments of an interesting and important nature. He also tested the iron plates and angle-bars used in the construction of H.M. armour-cased ships "Black Prince" and "Hector." The Scottish Shipbuilders' Association, having obtained the sanction of Messrs. Napier for the results to be laid before it, Kirkaldy forthwith prepared a Paper. The reception given to this effort led to the publication, in 1862, of the tests in a more extended form as a book, entitled "Results of an Experimental Inquiry into the Tensile Strength and other Properties of various kinds of Wrought Iron and Steel."¹ Some of the investigations recorded in that work are worthy of particular mention on account of the far-reaching consequences which they were the means of inaugurating. The most important was the service David Kirkaldy rendered in discovering, and placing on record therein, the effects of oil-hardening upon the properties and behaviour of steel. It had not previously been imagined that by heating steel and cooling it in oil its strength would be greatly enhanced without sacrificing its toughness. Knowing the importance of this process of oil-hardening, he took out a provisional patent for its application.

¹ This book is in the Library of the Institution.

In 1864 the Institution of Engineers in Scotland awarded him a gold medal for his communication "Experiments on Iron and Steel."¹ It may be mentioned that in 1857 Kirkaldy had a share with several others in the inception of that Institution. Another service was rendered to engineering knowledge by the publication of the results of his researches as to the "effects of shape" on the behaviour of metals, one outcome of these results being the adoption of an improved form of bolt for securing the armour plates of ships.

The experience thus gained, coupled with the success of his book, encouraged Kirkaldy to study the question of testing more deeply. After anxious consideration, he determined to erect a special testing-machine at his own cost, and to devote all his energy to the investigation of the mechanical properties of materials used in the constructive arts. He had resigned his post at Messrs. Napier's towards the close of 1861, after being in their service nineteen years, and had devoted two and a half years to the study first of the nature of the tests which would be required for the various materials, and then of the mechanical difficulties to be overcome in a machine which would be suitable for the full range of such tests, and at the same time very accurate and delicate in its action. The construction of his testing-machine was commenced in June, 1864, but was not finished until September, 1865, the long delay in making it causing him great anxiety and considerable pecuniary loss. The machine was erected in premises in The Grove, off Southwark Street, London, and public testing operations were commenced on the 1st January, 1866.

For many years Kirkaldy experienced great difficulties; his testing work was opposed by interested parties and prejudice had to be overcome. Although essentially a man of peace, he found himself on several occasions driven to defend himself against unjust attacks. Working quietly for many years, he carried out a vast number of experiments, and was the means of introducing many useful and important improvements; for example, in the form and proportions of bridge-link eyes, tie-rod ends, the true relations of welding, the shape of railway axles, and also in a great many details of engines of different kinds, the form of coupling gear, and hooks and screws for railway work, in which he was able to increase the strength considerably while reducing the weight. His experiments on riveted joints led gradually to great modifications and consequent improvement in the style of riveting for bridge-work. In the face of severe opposition he

¹ Transactions of the Institution of Engineers in Scotland, vol. vi. p. 27.
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proved the importance of drilling holes in steel in preference to punching, fearlessly pointing out the detrimental effect and the risk of punching holes.

As time went on Kirkaldy found that it was desirable to obtain larger premises, and, in order to have works adapted for his requirements, he decided to build. Selecting a site in Southwark Street (No. 99), he erected the present premises; the machinery was moved and re-erected there, and testing operations were renewed on the 1st January, 1874. No expense nor trouble was spared to render every department as perfect as possible, and from a merely business point of view he invested too much in apparatus and tools; but his enthusiasm for experimental research remained so keen that even during the last year of his life he cheerfully laid out a considerable amount on new machinery and tools in order to be able to carry out work more promptly. Among his more recent work mention may be made of an interesting series of experiments on the condition of steel rails after long-continued service, for which he received the thanks of several leading railway engineers.

In December, 1888, Kirkaldy was deeply gratified by a notification from the Court of the Worshipful Company of Turners that it had been resolved to confer upon him the Honorary Freedom and Livery of the Company in recognition of his life-work. The Freedom of the City of London also accompanied this honour. In all his trials he was cheered by the friendship of those who valued his labours and appreciated the sterling honesty of the man. Imbued with a lofty sense of truth and honour, ardently striving to carry out his work impartially, he was almost recklessly regardless of consequences. He would unflinchingly act up to what he considered right, often seeing clearly in advance that it would entail serious pecuniary loss and also tend to increase prejudice against him and his work. Realizing this, as he did, it is the more to his credit that he would not turn or prevaricate in order to gain support. His sensitive nervous system rendered it specially hard to bear the many worries inseparable from the position he had devoted himself to fill. In Kirkaldy's case the office of judge, ever considered a difficult one, was rendered more arduous not only by his staking everything he possessed in providing apparatus and premises, as an additional guarantee of responsibility, and by carrying out tests personally, but also by his being dependent for his livelihood upon the support of the persons who came to him often to settle very important issues. He fearlessly and consistently acted up to what appeared to

him to be right, and he lived long enough to see his work widely acknowledged. While unflinching in his professional life, privately he always retained his genial and lovable nature. Probably many misunderstood him simply through not knowing him. He was so scrupulous, even jealous, in maintaining the line of action which he had marked out for himself that he could not easily brook dictation or thwarting. One of his strong points was a desire for, and adherence to, Standards. When inaugurating his elaborately complete system of testing materials, the ground was clear, and every minute detail was carefully considered by him before adopting his standards. He was an ardent advocate of the adoption by engineers of definite, carefully-sifted, standard specifications, standard sections for rails, and uniform requirements for steel axles, locomotive and carriage tires, &c., all of which he considered would prove of immense advantage to British manufacturers, as they could then readily work up their productions to a given uniform standard. He had always looked forward to publishing a summary of his experimental work, so as to render it accessible to the profession. The opposition he had to contend against delayed the fulfilment of this intention, and ultimately he was glad to leave the work to his son, Mr. William G. Kirkaldy, whom he assisted in its compilation. The book, entitled "Strength and Properties of Materials, with description of the System of Testing," was published in 1891.¹

During the last year or two his health failed considerably; but he was cheerful and genial to the last, and took pleasure in knowing details of experiments, although for several months he was physically unable to carry out tests personally. From about September, 1896, he gradually became weaker, but his mental faculties remained wonderfully clear. He passed away peacefully in the early morning of the 25th January, 1897.

Mr. Kirkaldy was elected a Member on the 3rd March, 1885.

ALFRED RUMBALL, born in London on the 10th August, 1831, was the youngest son of Mr. Thomas Rumball, of Epping, and the stepson of Captain A. Vere Drury, R.N. He was privately educated at Mortlake and at an early age became a pupil of his brother, Mr. Thomas Rumball. Subsequently he was for seven years in the office of Mr. Thomas Bartlett,² who was then engaged on the construction of the London section of the Great Northern Railway for

¹ This work is in the library of the Institution

² Minutes of Proceedings Inst. C.E., vol. xxiv. p. 526. Google

Mr. Brassey.¹ In September, 1852, he accompanied his brother, who had been appointed Engineer-in-Chief of the Peninsula Railway of Portugal, now forming part of the Royal Portuguese Railways, and was employed as Assistant Engineer, having charge of the section of that line from Lisbon to Santarem. On the completion of that engagement he was appointed Assistant Engineer under Mr. George Neumann on the Victor Emanuel Railway, then being constructed by Mr. Brassey. He was entrusted with the superintendence of 12 miles of that line, and the manner in which he carried out his work was highly approved by Mr. Brassey.

In 1858 Mr. Rumball was appointed by Mr. Charles Vignoles,² Past-President, a District Engineer on the Bilbao and Tudela Railway, on which he remained until 1862.

In that year he was engaged by his brother, who had been appointed Engineer-in-Chief of the Buenos Ayres Great Southern Railway, as Resident Engineer, and it was under his supervision that the first section of that line, from Buenos Ayres to Chascomus, was completed by Messrs. Peto and Betts. Subsequently he carried out the next section of the line, to Dolores, without the intervention of a contractor.

On his return to England, in 1872, Mr. Rumball commenced practice on his own account in Parliament Street, and afterwards in Victoria Street. In 1873 he was appointed Consulting Engineer to the Argentine Government Railway Commission, during the construction of the Central Northern Argentine Railway and of the Rio Cuarto line. That post he held for four years. In 1880 he was deputed by Mr. Thomas Rumball to proceed to Santos and report upon the contemplated improvements in that city, and on his report a company was formed called The City of Santos Improvements Company, he being retained as Engineer.

In 1883 Mr. Rumball was appointed Engineer-in-Chief of the Brazil Great Southern Railway, which was completed under his direction, the contract being taken by Messrs. Cutbill and Co. At the time of his sudden death, on the 17th December, 1896, he was engaged in preparing plans for the extension of that line. From 1889 he also acted as Engineer-in-Chief to the Cordova and North Western Railway, which was completed under his superintendence, the contractors being Messrs. Perry, Cutbill, De Lungo and Co.

In addition to the works above referred to, Mr. Rumball visited Russia, Sweden, Spain and Italy, for the purpose of reporting on engineering projects in those countries, and, in conjunction with

¹ Minutes of Proceedings Inst. C.E., vol. xxxiii. p. 246.

² *Ibid.*, vol. xlivi. p. 806.

Mr. Robert Bruce Bell,¹ elaborated in 1875 a scheme for supplying the city of Turin with water. He also devoted much time, in conjunction with Mr. Abernethy,² Past-President, in resuscitating the scheme for new docks on the Thames at Dagenham.

Early in 1860 Mr. Rumball married Jessie, youngest daughter of the late Mr. D. Finlayson, of the firm of Messrs. Finlayson, Bousfield and Co. of Johnstone, N.B., flax spinners. He was elected an Associate on the 14th April, 1863, and was transferred to the class of Members on the 17th December, 1866. In 1878 and 1879 he rendered service to the Institution by auditing the accounts.

DAVID LEONARD BARNES³ was born at Smithfield, Rhode Island, near Providence, U.S., on the 23rd August, 1858. When he was only about eleven his father died, and young Barnes soon had to exercise self-reliance and judgment. At fifteen he began work with a civil engineer, and was occupied two or three years in surveys. In 1876 he entered Brown University, and spent three years there and at the Massachusetts Institute of Technology, as a special student, doing engineering work in vacations. In 1879 he began work in locomotive shops, and during the following eight years served in various capacities in the Hinckley, the Rome and the Rhode Island Works. He eventually became Chief Draughtsman and Mechanical Engineer at the Rhode Island Works. In 1887 he began to practise as a consulting engineer, doing work of some importance for various clients, and for the last eight years he maintained an office as consulting engineer in Chicago, with a New York connection, and was also on the staff of the *Railroad Gazette*, not merely as a writer, but with editorial responsibility, and largely influenced the conduct of that paper in mechanical matters, and especially in locomotive engineering.

Mr. Barnes' work as a consulting engineer covered the design, testing, and inspection of railroad rolling stock. As the Chicago and South Side Rapid Transit Railroad (Alley Elevated) neared completion, he was entrusted with the general supervision of the design and construction of its rolling equipment, signalling, lighting and shop plant. His most important recent work was as Consulting Engineer for the Baldwin Locomotive Works and the Westinghouse Electric and Manufacturing Company in designing

¹ Minutes of Proceedings Inst. C.E., vol. lxxv. p. 293.

² *Ibid.*, vol. cxxiv. p. 402.

³ This account has been abridged from a notice which appeared in the *Railroad Gazette*, New York, 25 December, 1896.

a set of standard electric locomotives. He threw himself into this with enthusiasm, and brought to bear upon it an intimate knowledge of the requirements of railroad work, a set of designs being produced, remarkable for simplicity and adaptability to the actual work of hauling trains. Mr. Barnes did not claim that he alone was responsible for these designs; he was the last man to claim more than his due, or to belittle the part which others had in his work.

Mr. Barnes died in New York on the 15th December, 1896. His activity during the last eight years was prodigious; probably it killed him. He wrote much, not only unsigned articles in the *Railroad Gazette*, but over his own name in the transactions of the various technical societies to which he belonged.¹ He was fond of writing, and always had two or three articles and papers on hand in various stages of preparation. But he had little enjoyment in mere composition. Writing was to him only a means of conveying thought, and had he lived he would have made a reputation for clear and energetic expression. His numerous papers and reports on locomotive engineering, on car-construction, and on electricity as a motive power for railroad working, form a body of scientific literature of permanent value, not only in what he said, but in what he suggested. The only books which bear his name are the revised edition of "Compound Locomotives" by Arthur T. Woods, and an excellent treatise on "Electric Locomotives."

Physically and mentally Mr. Barnes was a man of unusual strength and energy; no amount of work discouraged him, and being quick and systematic he accomplished much. He was a natural mathematician, had strong powers of analysis, reasoning and invention, and loved to use his faculties. One of the most striking qualities of his mind was its lucidity. He was enthusiastic, candid and courageous, and, being human, was sometimes wrong, but he was always stimulating and suggestive. And he never stuck to an error because it was his; he had the truly scientific love of truth. He had great poise; excitement only steadied him, and even when he was angry, which was seldom, he was temperate in speech and conduct. His bright spirits and his sweetness of temper and manner, endeared him to old and young, and he has no more sincere mourners than the little children who knew him.

Mr. Barnes was elected an Associate Member on the 3rd March, 1896.

¹ See Transactions of the American Society of Civil Engineers, vol. xxix. p. 385, and Transactions of the American Society of Mechanical Engineers, vol. xvi. p. 249.

GEORGE FINDLATER CLEMENTS, who died on the 7th June, 1896, was the son of the late Mr. John Findlater Clements, of Bathurst, N.S.W., and was born on the 23rd February, 1868. He was educated at All Saints College, Bathurst, and at the age of seventeen entered the Government Railway Service, being located at Bathurst under Mr. J. F. Watson, the divisional engineer. While passing through the workshops, Mr. Clements took every opportunity of attending technical classes for geometrical drawing, physics, &c., and was early employed in the field in surveying, setting out and estimating for colliery sidings and other works, the details of which he quickly mastered. In 1890 he secured one of the cadetships offered for competition by the New South Wales Government, the possession of which entitled him to two years' study in England. During that period he acquired a practical knowledge of electrical engineering in the works of Messrs. Siemens Brothers and was engaged in the construction of the Guernsey electric tramways.

Mr. Clements returned to New South Wales in 1892, entering the electrical engineering branch of the government railways under Mr. P. B. Elwell, for whom he superintended the equipment of the military road electric tramway, proving himself capable of carrying out such works in a most satisfactory manner. Had he lived he would probably have distinguished himself in this field, being a young man of exceptional ability and promise. Mr. Clements was elected an Associate Member on the 1st May, 1894.

NAPOLEON EDWARD DREW, born in Smyrna on the 16th January, 1864, was the only child of Mr. Edward Alexander Drew, who was then engaged on the construction of the Smyrna and Aidin Railway. After being educated at the Lycée Henri IV. in Paris, and at Tonbridge School, the subject of this notice was articled in 1884 to Mr. J. H. Watson Buck, one of the Resident Engineers of the London and North Western Railway. From 1888 to 1892 he was employed on the construction of the Midland Railway of Uruguay for Messrs. Perry, Cutbill, Son and De Lungo.

On the completion of that work Mr. Drew returned home, where he remained for some time. In January, 1896, he proceeded to Pernambuco, having obtained the appointment of Assistant Resident Engineer on the Recife and São Francisco Railway. He

had held that post for only twelve months when he succumbed to yellow fever on the 17th January, 1897. Mr. Drew was known as a willing and energetic officer and his amiable disposition made him a general favourite. He was a good linguist, speaking French, Spanish and Portuguese. He was elected an Associate Member on the 6th May, 1890.

NICHOLAS DUNSCOMBE, born on the 25th May, 1867, was the son of Mr. Parker Dunscombe, of King William's Town, co. Cork. He was educated at the Isle of Man College. In August 1887, he was articled to his uncle, Mr. Clement Dunscombe, who was at that time City Engineer of Liverpool, and while serving his pupilage, went through the course of engineering at University College, Liverpool. In December, 1890, he was appointed general assistant in the Borough Engineer's Office, Cheltenham, where he remained until the spring of 1894, when he was elected, from a large number of candidates, Borough Engineer to the Corporation of Chesterfield. That appointment he held until his death, which took place at Chesterfield on the 18th September, 1896, after a few days' illness from pneumonia.

Mr. Dunscombe had an excellent engineering training, had gained considerable experience in municipal work, and always discharged his duties in a highly creditable manner. He was elected an Associate Member on the 6th December, 1892.

JAMES ROBINSON was born at Durham on the 21st February, 1852, and in 1867 was articled to the late Mr. William Crozier, County Surveyor of Durham, with whom he remained nine years. During that period he not only acquired experience of the duties of a County Surveyor, but, in connection with the private practice of Mr. Crozier, was occupied with the design and superintendence of various important buildings and other works.

In 1875 Mr. Robinson was selected from a large number of competitors for the post of County Surveyor of Hants, which office he continued to hold till the time of his death. He carried out numerous important works for the county, including new lattice-girder and other bridges, police stations, and additions to the asylum. He also designed and carried out the County

Buildings at Winchester, a large block in the late Gothic style, planned on a difficult site, while the main roads and footpaths throughout the county were considerably improved during the time they were in his charge. In addition to this work, Mr. Robinson had a private practice and in that connection built the Volunteer Head-Quarters at Winchester and constructed four steel bridges across the Basingstoke Canal for the Hartley Wintney Rural District Council. In 1892-93 he held the office of President of the County Surveyors' Society.

Mr. Robinson died at Bognor on the 2nd October, 1896, after an illness of seven weeks. He was elected an Associate Member on the 12th January, 1892.

HERBERT WILFRID SKINNER, born on the 5th April, 1866, entered the Harbours and Rivers Branch of the Public Works Department of New South Wales as a cadet in 1881. For some years he was engaged on improvement and training works for Richmond and Cook Rivers, and on various works for the Imperial Naval Station at Garden Island, Sydney. In 1890 he was appointed resident engineer, under Mr. Alfred Williams, on improvements to Sydney Harbour, undertaken on behalf of the Peninsular and Oriental Steam Navigation Company, the Orient, the North German Lloyd, the Messageries-Maritimes, and other shipping companies using the port. He was also engaged in a similar capacity in constructing jetties and floating stages for the New South Wales Marine Board, and on the maintenance of Macquarie and Hornby Lighthouses, and the South Head Signal Station. He carried out numerous marine surveys and was responsible for the testing of all cement used by the Harbours and Rivers Branch.

Mr. Skinner died suddenly on the 7th July, 1896. He was elected an Associate Member on the 6th February, 1894.

THOMAS ALEXIS DASH, born on the 22nd September, 1827, was the son of Mr. Thomas Dash, late of Clewer House, near Windsor, and of Wokingham, Berks. After being educated at Eton he was articled to Mr. Henry Walter, land surveyor, of Wokingham and of Old Windsor. On the death of that gentleman

he was transferred, in 1846, to the office of Mr. G. H. Saunders,¹ of Westminster, under whom he was engaged for five years on surveys for the Birmingham, Wolverhampton and Dudley Railway, the Furness Railway and Barrow Harbour, and the drainage of the Essex marshes. He was then for twelve months in the service of Mr. John Clutton,² of Whitehall Place.

In the spring of 1852, Mr. Dash entered H.M. Office of Works, and in 1857 was appointed Land Surveyor to the Commissioners of Works and Public Buildings. During the thirty years he held that post, Kennington, Victoria and Battersea Parks were acquired and laid out by the Government, and the sites of the Royal Courts of Justice and of many Government Offices in London and the country were purchased, the surveying and parliamentary work being carried out under his supervision. He was also responsible for the land surveying in connection with various alterations from time to time in the Royal parks and gardens, and for the record plans relating to their boundaries.

Mr. Dash, having attained his maximum number of years' service at the Office of Works, retired in 1887. He died at Woodham, near Weybridge, on the 20th March, 1897. He was elected an Associate on the 1st March, 1881.

ROBERT WARNER was born on the 10th September, 1815, at Jewin Crescent, Cripplegate, at the business house which was also the residence of his father, then the head of the firm of John Warner and Sons, bellfounders, and the descendant of a family of Quakers, following in an unbroken line from the time of George Fox, about the middle of the seventeenth century.

The subject of this notice was educated at the Friends' School at Epping and, after serving an apprenticeship at Chelmsford, entered his father's business, of which he ultimately became the head. Amongst other work carried out by the firm was the casting of the bells for the Clock Tower of the Houses of Parliament. The hour bell, weighing 13 tons 11 cwt., was named "Big Ben" after Sir Benjamin Hall, then First Commissioner of Works. The quarters are struck upon four smaller bells, weighing from 4 tons to 1 ton each. The tune, or rather succession of notes, played by the quarter bells, consists of a series of ingenious variations of a

¹ Minutes of Proceedings Inst. C.E., vol. xvii. p. 105.

² *Ibid.*, vol. cxv. p. 430.

passage which may be found in the opening symphony of the air "I know that my Redeemer liveth" in the *Messiah*. The large bell cracked before leaving the foundry and was recast by Mears. After having been hung for some time Big Ben II. also gave way, and for three years the hours were struck upon the largest quarter-bell. Eventually, however, it was again brought into use, having been turned round so as to present a fresh striking-place to the hammer. The flaw does not show any signs of going farther.¹

A strictly engineering work carried out by Mr. Warner was the construction of a breakwater at Walton-on-the-Naze for the protection of his property at that place. In 1842 he founded the United Kingdom Temperance and General Provident Institution, of which he was Chairman for fifty-two years. He was well known as one of the first successful growers of orchids in this country and published an exhaustive treatise on "Select Orchidaceous Plants," being shortly afterwards elected a Fellow of the Linnean Society. At the time of his death he was the "Father" of the Worshipful Company of Founders, being the oldest member of the Court.

Mr. Warner died at his residence, Widford Lodge, near Chelmsford, on the 17th December, 1896, at the age of eighty-one. He was elected an Associate on the 27th May, 1879.

. The following deaths have also been made known since the 18th February, 1897:—

Members.

CARR, ROBERT; born 29 November, 1827; died 6 April, 1897.	JONES, FRANCIS; died 19 February, 1897, aged 81.
CRAIG, JAMES; born 24 July, 1844; died 3 May, 1897.	MESSENT, PHILIP JOHN; born 7 December, 1830; died 5 April, 1897.
FORREST, JACOB; died February, 1897.	MORNING, CARLOS ALBERTO; born 18 June, 1837; died 26 February, 1897.
HUNT, WILLIAM; born 8 January, 1843; died 29 March, 1897.	SHOPLAND, JAMES REW; born 17 December, 1841; died 22 April, 1897.

Associate Members.

HORN, THOMAS WILLIAM, Jun.; born 21 April, 1864; died 24 April, 1897.	WYLLIE, GEORGE, F.C.H.; born 9 October, 1860; died 23 December, 1896.
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Information as to the professional career and personal characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 12 May, 1897.

¹ Wheatley's "London Past and Present," vol. ii. p. 243.

SECT. III.

**ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS
AND PERIODICALS.**

Resistance of Bars under Stresses parallel but eccentric to their neutral Axes. DUPUY.

(*Annales des Ponts et Chaussées*, September, 1896, p. 223.)

This is an analytical consideration—accompanied by tests with a Rabut apparatus—of the distribution of stresses in bracing and similar bars when subjected to stresses in a line parallel but eccentric to the neutral axes of the bars. Both tee bars and flat bars are considered under these conditions, and the stresses are applied to the ends of the bars through flat plates riveted to them, these plates representing the centre web plates of a girder. The stresses in different parts of these bars are calculated under tension and compression, and these calculated results are compared with those obtained by means of a Rabut apparatus. (The Rabut apparatus is a delicate arrangement for measuring the elongation or contraction of the metal between any two points of a member under stress, and in these experiments the distance apart of such points was about 8 inches.)

The article is very fully illustrated by means of cuts and plotted curves, showing the close agreement between the calculated stresses and those obtained by means of the Rabut apparatus. The Author draws the following conclusions:—The intensity of the stresses in different parts of the bar depends largely on the distance between the line of action of the applied force and the neutral axis of the bar, and in certain cases a stress of opposite sign may be induced in the extreme fibres of the bar, and these induced stresses may much exceed the average stress. The greatest bending moment with the bar in tension occurs at the ends; but, with the bar under compression, it is at the centre. In these cases ribbed bars are preferable to flat bars, and tee bars to channels, if it is desired to relieve the riveting at the ends. Where bracing bars in compression and tension cross, rivets passing through both the bars at the crossing relieve the stresses of the bar under compression, and increase those in the bar under tension.

R. B. M.

Primary Triangulation executed by the United States Geological Survey. H. GANNETT.

(Sixteenth Annual Report of the United States Geological Survey, 1896, part i.
p. 877.)

Since 1882 primary triangulation has been carried out by the United States Geological Survey on an extensive scale, in order to furnish ultimate control for maps. During the thirteen years, 1882 to 1894, no fewer than 1,295 primary points have been fixed, furnishing control for fully 500,000 square miles of country.

Twelve base-lines have been measured, their lengths being as shown in the following Table:—

Locality.	Year.	Length in Miles.
Wingate, New Mexico	1881	4·20
Bozeman, Montana	1883	4·56
Austin, Texas	1884	6·40
Fort Smith, Arkansas	1887	2·84
Little Rock, Arkansas	1888	3·72
Spearville, Kansas	1889	7·10
Albany, Texas	1889	9·00
Sierra Blanca, Texas	1890	4·60
Boise, Idaho	1890	4·75
Aspen, Colorado	1891	1·00
Laramie, Wyoming	1892	2·50
Rapid, South Dakota	1893	5·00

The first three base-lines were measured with secondary base-bars. Since then steel tapes 300 feet in length, under constant tension, have been employed. Since 1889 the instruments used have been 8-inch theodolites reading by microscope to two seconds. The signals used are ordinary tripods and poles, the tripod being swathed in cotton to facilitate finding it. In wooded regions tripods composed of three trees trimmed up are sometimes used. In the Rocky Mountains a common signal is a cairn of stones upon a summit. The permanent marks left to indicate the stations consist of copper bolts set in ledges, holes drilled in ledges, stone posts, buried bottles with stones set over them, and cairns of stones, upon the largest of which inscriptions have been marked. The total cost of the triangulation, including base-measurement, was £80,000, an average per year of £6,000, and an average per station of about £60. The average cost of primary triangulation is about 3s. 4d. per square mile. Full details are given of the triangulation carried out in the various States.

B. H. R.

History of the Cross-hairs of Theodolites. E. HAMMER.

(Zeitschrift für Vermessungswesen, 1896, p. 513.)

For a long time there has been a controversy as to who was the first to employ cross-hairs in the focus of the telescopes of surveying instruments; whether it was the Italians Generini, Malvasia, or Montanari, the Frenchmen Morin, Auzout, or Pickard, or the Dutchman Huygens. As a matter of fact it was none of these, but William Gascoigne in England, about the year 1640 or a little earlier. He fell in 1644, at the age of twenty-four, in the Battle of Marston Moor.

With reference to the material used for the cross-hairs, it is frequently assumed that spiders' web was in use from the beginning. This was not the case. Gascoigne speaks only of hair and thread. Auzout and Pickard speak of *cheveux*, and Montanari, in his "Livella diottrica" 1674, of *capelli*. In 1662 Malvasia employed, besides hairs and vegetable fibres, silver wires. In the middle of the last century, glass and mica plates with engraved lines were first used in place of cross-hairs. They were described by Brander in 1772, and were used by Breithaupt in 1780. Spiders' webs were not used until 1775, when their use was advocated by Fontana. In 1818 Struve employed fine glass threads, and of recent years platinum wires have been used. The cross-wires, too, have, in many cases, been replaced by fine points of metal, or of glass, reaching only to the centre of the field of sight.

B. H. B.

Application of Photography to Surveying. J. S. DENNIS.

(Engineering News, New York, vol. xxxvi., 1896, p. 331.)

In a Paper read at the Denver meeting of the American Society of Irrigation Engineers, the Author gave the results of photographic surveys made in Canada. The method was adopted in 1888 in the main range of the Rocky Mountains near the Canadian Pacific Railway, and 250 square miles were surveyed in that year. From that time, from 375 to 500 square miles were thus surveyed each year until the total area covered amounted, at the end of 1892, to 2,025 square miles. The surveying party consisted of a topographer, an assistant, a packer and a labourer, the average area surveyed being 8 square miles per day. The results are plotted on a scale of 1 to 20,000, and reduced for publication to half that scale. A published sheet, taken as an illustration of practice, represents an area of 63 square miles. The survey was made from six stations inside the sheet and eleven stations outside, and 1,075 points were fixed by intersections from thirty-five photo-

graphic views. This corresponds to seventeen points per square mile. The expenses of the season in 1892 were as follows:—

	£	s.	d.
Packer, 8s. per day; labourer, 6s. per day . . .	85	16	0
Transportation	115	14	0
Living expenses	78	18	0
Miscellaneous	15	7	0
Total	<u>295</u>	<u>15</u>	<u>0</u>

To this must be added £300 per annum for the salary of the topographer, and £146 for that of his assistant; and the total is £741 15s. as the cost of surveying 500 square miles in one year. This is equivalent to about £1 10s. per square mile, or $\frac{1}{2}d.$ per acre. The Author believes that the method could be successfully and economically applied to surveys made in connection with irrigation enterprises.

B. H. B.

Apparatus and Methods for Testing Portland Cement. M. GARY.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1896, p. 155.)

In view of the revision of the "Standards for the Uniform Testing of Portland Cement" by order of the Prussian Ministry of Public Works, the Association of German Portland Cement Manufacturers has appointed a Commission, which has carried out some investigations in conjunction with the Royal Testing Laboratory at Berlin. The present Paper describes the methods and apparatus in use at the Royal Laboratory, and suggestions for the improvement of the "Standards."

Time of Setting.—The "Standards" specify: "The cement shall be mixed with water (from 27 per cent. to 30 per cent.) to form a stiff paste from which a cake 1·5 centimetre thick shall be made. As soon as the cake is sufficiently hard to resist a slight pressure with the finger-nail the cement shall be considered set. Slow-setting cements shall be stirred for three minutes, quick-setting cements one minute." In the Royal Laboratory all cements are at first stirred three minutes. If any cement begins to set in less time, it is stirred one-and-a-half minute, since experience has shown that no workman, however skilled, can uniformly mix 300 grams or 400 grams (10 ozs. or 14 ozs.) of cement with water in one minute. The quantity of water used in mixing has a great influence on the time of setting. At the Royal Laboratory the cement is mixed with water until it can run off from the mixing knife in long thin threads like syrup. This consistency can be determined so closely that, with practice, a difference of 0·5 per cent. of water can be observed. The quantity of water varies between 32 per cent. and 38 per cent. To this mixture dry

cement is gradually added, until it begins to collect in balls, when the pressure-test is applied. The Vicat needle apparatus for the accurate determination of the time of setting is described. The influence of temperature and the hygrometric state of the air on the time of setting are discussed, together with the corresponding precautions taken at the Royal Laboratory.

Constancy of Volume.—The "Standards" specify: "Portland cement shall preserve constancy of volume. A thin cake made on a flat glass plate, kept in moist air for twenty-four hours, then placed in water, shall afterwards show neither curvature nor cracks at the edges." Before immersion in water the thin cakes made at the Royal Laboratory are kept in a zinc-lined box, the lid of which has on its inner side thick felt, which can be kept moistened with water. The covering of the test-cakes with damp cloths is not recommended.

Fineness of Grinding.—"Portland cement shall be ground so fine that a sample shall leave behind not more than 10 per cent. on a sieve of 900 meshes per square centimetre (5,800 meshes per square inch), the diameter of the wire being half the width of the mesh." At present it is impossible to obtain sieves to suit the requirements of the "Standards"; it would therefore be advantageous to order the sieve wire-gauze from one firm, so that uniformity may be attained. According to the "Standards," the width of mesh should be 0.222 millimetre, the diameter of the wire 0.111 millimetre. In the sieves used at the Royal Laboratory these dimensions are respectively 0.230 millimetre and 0.094 millimetre.

Strength Tests.—Test specimens, 5 square centimetres and 50 square centimetres sectional area respectively for tension and compression, are prepared at the Royal Laboratory by means of five Böhme hammer-machines. Years of experience have shown that the objections raised in some quarters against machine-made test-specimens cannot be substantiated. The differences of the strengths of specimens prepared by the different hammers lie well within the allowable limits of error.

The arrangement of the mould, base-plate, and cover-box has great influence on the strength of the specimens produced. If the mould lies loose on the table while the ramming is going on, the material gets pressed between the top of the mould and its cover-box. Dr. Goslich designed an arrangement for clamping mould, base-plate, and cover-box firmly together; and later Prof. Martens designed an improved and simplified apparatus, which can be quickly worked and easily cleaned. Experiments show that specimens consisting of 1 part cement and 3 parts sand made in the new moulds are 2.5 per cent. stronger in tension and 5 per cent. stronger in compression than specimens made in the old moulds, and that greater uniformity is attained with a number of similar specimens. The manner in which the ram is guided through the cover-box has an influence on the strength of specimens. After a number of experiments, a ram going quite loosely through the cover-box has been adopted.

The calibration of the Michaëlis lever tension-machine, and of the Amsler-Laffon 30-ton press, is fully described.

"To ensure uniformity of results, the sand used shall be clean quartz sand, washed and dried, and which shall pass through a sieve of 60 meshes per square centimetre (387 meshes per square inch), but be retained by a sieve of 120 meshes per square centimetre (774 meshes per square inch). The wires shall be 0·38 millimetre and 0·32 millimetre diameter respectively." The sieves obtained in the usual way from the makers do not at all satisfy the requirements of the "Standards." Two sieves at the Royal Laboratory, each nominally 120-mesh, contain 121 and 129 meshes per square centimetre respectively, and pass 35·4 per cent. and 4·6 per cent. of normal sand.

Preparation of Cement-Sand Specimens.—The "Standards" specify a mixture of 250 grams cement, 750 grams sand, and 100 grams water. The Royal Laboratory find that in most cases 10 per cent. of water, as specified by the "Standards," is too much, as some of the finer cement particles are washed away by the excess of water, and the strength of the specimen is thereby reduced. Formulas for the quantities of water to be used in different cases are given.

The Paper is copiously illustrated by tables, drawings of apparatus, diagrams, and reproductions from photographs.

A. S.

The Testing of Slag-Cement in Regard to Expansion, according to Austrian Rules. KARL BERGER.

(*Mittheilungen des k. k. technologischen Gewerbe-Museums in Wien*, 1896, p. 317.)

The successful results which have occasionally ensued from the use of slag-cement have induced certain authorities to permit of the supply of this material on equal terms with Portland cement. How far this may be justifiable is not discussed, but it is pointed out that cement of this character should be subjected to special conditions, though this is not the case under the Austrian normal regulations for the testing of Portland cement. As respects fineness of grinding and tensile strength, the Austrian samples of slag-cement are capable of satisfying all the requirements laid down for Portland cement, and in some of these tests the slag-cement is so greatly superior as to ensure its acceptance, but if tested neat it is liable to become hair-cracked to a far greater extent than pats of neat Portland, and when exposed to the hot-air test, and more especially to the boiling-test, slag-cement often gives very unsatisfactory results. The cracking of the pats exactly coincides with the effects observed in the case of over-limed, hot cements, and the causes of this cracking at the edges of the pats in the case of slag-cement are considered. It is frequently found that in contradistinction to the experience with Portland cement, a slag-cement

which proves imperfect when tested neat, will give very satisfactory results when tested with three parts of standard sand. The expansion is probably caused by minute particles of imperfectly-slaked lime, which, owing to the extremely fine grinding in the case of the neat slag-cement, find no space for increase in bulk and thus lead to disruption, whereas when used with sand the cavities between the sand-grains afford sufficient space for the increase of volume in the cement.

G. R. R.

Practical Observations respecting the Preparation of Waterproof Cements. THEODOR KOLLER.

(*Annalen für Gewerbe und Bauwesen*, 1 March, 1897, p. 95.)

The various qualities needed in cements employed for uniting substances of different kinds are discussed, and it is pointed out that the properties required in cements are so diverse that no single material could satisfy all the demands. One of the objects very frequently sought for is that the cement in question should be waterproof, and among the best of such substances are the compounds of boiled oil, or an oil varnish, with whiting, red lead, litharge, or calcined magnesia. These compounds all act by the saponification of the fatty matters, the acids present in which combine to form salts of lead, zinc, &c. All of these cements, though they resist water admirably, are somewhat slow in drying. The resinous cements very nearly equal the foregoing in value and importance, and in the same category must be placed the cements composed of caoutchouc or gutta-percha, which are especially useful, owing to their power of resisting chemical action. The Author gives numerous receipts for the production of cements of various descriptions suitable for many special purposes and for uniting and repairing all kinds of materials, keeping always in view the fact that the joint must not be liable to be acted upon by water. Special advantages are claimed for a cement composed of litharge and glycerine.

G. R. R.

Public Works of Roman Origin in Tunis. P. GAUCKLER.

(*Revue générale des Sciences*, 30 November, 1896, p. 954.)

Two things are imperatively needed for the colonization of Africa—water and roads. An account is given of the Roman embankments and dams, of which numerous remains are found in various parts of the country, serving to impound water for use in agriculture during the five rainless months. By means of photographs, the mode of construction and the vast scale of the works

carried out in ancient times for the storage and distribution of potable waters are explained. The aqueduct destined to supply Carthage with water is selected as an example of similar undertakings, and the network of military and trade roads is explained by reference to a map. Numerous illustrations are given of the public works, such as bridges, triumphal arches, temples and amphitheatres, of which ruins are found in great numbers, serving to show the importance of the province under Roman occupation.

G. R. R.

Public Works in Tunis under the French Protectorate.

E. DE FAGES.

(*Revue générale des Sciences*, 15 December, 1896, p. 1165.

The condition of public works in Tunis in the period anterior to the establishment of the protectorate is briefly considered. The lines of railway, waterworks, and lighthouses were the only undertakings of any importance. As early as 1883, however, a complete administrative department of public works was instituted, but it really only began its operations in 1886. The annual expenditure at the present time under this head amounts in all to about £180,000. Under the head of maritime ports, roads and tracks, railways, waterworks, municipal undertakings, and civil buildings, an account is given, illustrated by a map, and also by photographs, of the various constructions which have recently been carried out in Tunis. The estimated expenditure upon works in hand, or which will have been completed by the end of the present century, reaches nearly £6,000,000 sterling, apportioned as follows:—

	£
Maritime ports	1,520,000
Lighthouses and beacons	80,000
Macadamised roads	600,000
Railroads	2,600,000
New buildings	480,000
Waterworks and drainage	480,000
Municipal works, tramways, &c.	160,000

To provide for future expenditure, it is anticipated that Tunis will have to seek for a public loan.

G. R. R.

The St. Lawrence Bridge Competitions.

(Engineering News and American Railway Journal, 7 January, 1897, p. 7.)

In January, 1895, the Montreal Bridge Company issued an invitation to send in plans and estimates for the superstructure of a bridge carrying two tracks of ordinary railways, two electric tramways, a carriage road, and two footways. There was to be one cantilever span of 1,250 feet with 150 feet headway, two side spans of 500 feet, fifteen spans of 250 feet, and eighteen spans of smaller length. Prizes of \$1,000 and \$500 were advertised. Numerous designs were submitted from the United States, Canada, England, and Belgium, thirteen of which are illustrated. On 8 August, 1896, the two prizes were awarded to E. S. Shaw and A. L. Bowman for cantilever bridges, as also a special prize to J. W. Balet for a suspension bridge stiffened by a girder. Among the designs illustrated is one more of the latter type and three arch bridges, the remaining six being cantilever bridges. Descriptions and statements of estimates are contained in the notice.

M. A. E.

The Iron Viaduct over the Otterthal on the Ziegenrück-Hof Railway. E. BIEDERMANN.

(Zeitschrift für Bauwesen, 1896, p. 531.)

This viaduct is constructed on the American trestle-piers system, and is an instance for which that form is well adapted. The Paper is illustrated by a photo-gravure, from nature, of a portion of the viaduct, and by a number of detail drawings. The viaduct crosses a side valley of the Otterbach, which latter is a tributary of the Saale. The line is single, and is here on a curve of 200 metres (10 chains) radius, check rail timbers being laid throughout.

In the preliminary investigations it was estimated that the crossing of this side valley would, if made in embankment, cost 184,000 marks (£9,200), if in stone arch viaduct, 174,000 marks (£8,700), and by the method finally adopted and here described 110,000 marks (£5,500) (exclusive of permanent way).

The geological conditions were unfavourable to the adoption of masonry, the stone (*grauwacke*) of the locality being unsuitable and costly, and it was estimated that even the adoption of stone for the piers, with an iron superstructure, would add 30,000 marks (£1,500) to the cost as compared with a structure of iron throughout, excepting the abutments and the pier foundations of stone. The structure is divided up into six equal spans, or, more properly speaking, into eleven equal spans, as the width in elevation of each of the five piers, or closed spans, is equal to that of each open bay. The span of these is 10 metres

(32·81 feet), so that the total length of the viaduct between the masonry abutments is about 361 feet (110 metres). The trestle piers are each formed of four upright members, vertical in elevation, but splayed laterally on each face in cross-section, to a batter of about 1 in 10. In elevation the trestles are divided vertically into rectangles of 9 metres (29·5 feet) deep by fish-bellied framed struts and diagonal tie-rods. At their heads the uprights are tied transversely by a plate girder 0·4 metre (1·3 foot) deep, and in the saddles resting on these are the main girders which batter inwards 1 in 10, thus continuing upwards the line of rake of the trestles. Also the outside girder is higher than the inside one to allow for the cant of the curve. The platform is made up of transverse laid channel bars, and the width over all, outside balustrade, is about 5·30 metres (17·4 feet). The main girders are 0·94 metre (3·08 feet) deep between flanges, and the flanges 0·23 metre (0·75 foot) broad, their distance apart at upper flange-level being 2·0 metres (6·6 feet).

The greatest height of the viaduct, from the foundation of the masonry bases on which the trestles rest to rail-level, is about 35 $\frac{1}{2}$ metres (116·5 feet), and the average height is about 23 metres (75·5 feet).

A comparative Table is given of the cost of this viaduct as executed with wide trestle piers, and what it would have been with ordinary framed ironwork "tower" piers, the weights being 255 and 290 tons respectively. The trestle form of structure, on investigation, was found to be the most advantageous where the average height of the piers is about 20 metres (65·6 feet), but where the average height attains 30 metres (98·5 feet) and over, then tower piers with larger spans are the more economical.

The calculations for the structure are given; also the loading tests.

The cost of the structure, including permanent way, platform, stone bases to trestles and masonry abutments, amounted to 115,000 marks (£5,750), or 1,045 marks per metre (£47 15s. per lineal yard).

D. G.

The Opening of the Iron Gate of the Danube.

(Zeitschrift für Architektur und Ingenieurwesen, 1896, p. 165.)

This is a short article illustrated by the following diagrams, viz., a plan of the Danube where crossed by the rock reef known as the Iron Gate, a longitudinal section, to a very distorted scale, of the portion of the Danube affected by the regulation works in question, viz., between Stenka near Moldawa (about 30 miles below Belgrade), and the Iron Gate just below Orsova, and lastly a cross-section of the canal-cut at the Iron Gate. Near the latter place are numerous remains of works constructed by the Romans.

The desirability of improving the navigation must have always been evident, and in 1834 special attention was given to the subject, plans being got out by Paul Vasarhelyi, and later by Wex and Mensburger; but the conflicting interests of the numerous States bordering the Danube prevented anything definite being settled, and it was not until the conclusion of the Russo-Turkish war that it became practicable. In 1878, by the treaty of Berlin, it was arranged that Austria-Hungary should carry out the work, the future arising custom dues being secured to her as compensation. In 1888 the requisite capital of 9,000,000 guldens¹ as then estimated (£869,580) was voted, and on December 15th, 1890, the works were commenced. They were carried out under the direction of J. Hadyn, a Hungarian engineer.

The regulation works in question extend over the whole stretch of the stream between Stenka and Orsova, a length of about 100 kilometres (62 miles); the channel throughout is more or less confined and obstructed, frequent reefs of granite and limestone occurring, many of which rise above the low-water level or up to within a few inches of it. The regulation works include canals or cuts through the rock of altogether about 15 kilometres (9½ miles) length (exclusive of that at the Iron Gate).

At the Iron Gate there is a canal of 2,000 metres (1½ mile) long on the right bank of the river, and which cuts through the Prigrada reef. The breadth of the bottom of the canal is 72 metres (236 feet) and the depth (minimum?) is 3 metres (10 feet). It is enclosed between two dams, of which the top is 0·6 metre (2 feet) above the highest recorded flood-level. The dam on the left bank of the canal is 1,900 metres (2,077 yards) long, and that on the right 2,900 metres (3,170 yards), the space between the foot of each dam and the top edge of the canal being filled up with stone so high as to be above ordinary water-level.

For the navigation works there have been 320,000 cubic metres (418,560 cubic yards) of rock blasted and then dredged, and 130,000 square metres (155,480 square yards) of slope pitching laid. For the works at the Iron Gate there have been 380,000 cubic metres (497,040 cubic yards) of rock blasted, 560,000 cubic metres (732,480 cubic yards) of dams tipped and 100,000 square metres (119,600 square yards) of pitching laid. In the construction of the Iron Gate Canal the blasting was carried on in the dry, the water being dammed out and the site kept dry by centrifugal pumps until the completion of the work. The blasting for the canals at the various other points has been, however, done under water.

The time occupied on the works above described was three and a half years.

D. G.

¹ Austrian gulden assumed as £0·09662.

The Discharge of the St. Lawrence River.

Professor C. H. MCLEOD, M. Can. Soc. C.E.

(Transactions of the Canadian Society of Civil Engineers, January to June, 1896, p. 129.)

The extreme low water of the St. Lawrence in the autumn of 1895, directed especial attention to the variation in the discharge of the river. The only measurement of the flow of the river that had been made below Montreal, was that by Mr. W. J. Sproule, M. Can. Soc. C.E., under the direction of the Montreal Flood Commission in 1886. The Author, with the help of several others, decided to undertake the gauging of the river on the 13th and 14th November, 1895. On the first day the river was 7 inches above its lowest level, and it rose 3 inches while the work was in progress. The position chosen for the gauging was 40 miles below Montreal, where the river for about a mile above and below runs in a straight course and has a very uniform section and surface slope. Similar methods to those employed by Mr. Sproule were adopted, so that the results would be comparable throughout. The velocity observations were made by rod floats, of uniform section loaded with lead weights within tin cylinders, having the same section as the rods; they were immersed to depths ranging from 6 feet to $42\frac{1}{2}$ feet. The average velocities were obtained from the time of crossing the two ends of the course 3,000 feet apart. In the reduction of the observations the results were corrected by reference to a curve of velocities in a vertical section obtained with an "Amsler electrical current-meter. The reduced float velocities varied from 2.36 feet per second in the middle to 1.25 foot per second at the side.

The area of the cross-section in 1886 was 115,300 square feet, and the discharges 311,100 cubic feet per second, and in 1895, with the water-level 1 foot 9 inches lower, the cross-sectional area was 105,400 square feet and the discharge 216,600 cubic feet per second.

A. W. B.

The Improvement of the Delaware River. W. ATLEE.

(Journal of the Franklin Institute, December, 1896, p. 401.)

The Author of this Paper claims that the Delaware is the largest tidal river upon which such a comprehensive scheme of improvement as he here describes has been attempted. The portion of the river dealt with is divided into three parts: the portion above Philadelphia harbour, about 29 miles long, the portion including the harbour, six miles long, and the portion from Philadelphia to deep water in Delaware Bay, which is about 55 miles in length. On the first section the minimum depth in

the channel at mean low-water is now only 6 feet, and over this section there does not appear to be any immediate likelihood that the further deepening of the river will be proceeded with.

The proposed scheme for the second portion, which was adopted by Congress in 1890, involves the formation of a channel 2,000 feet wide, with a depth of 26 feet at mean low-water over half the width, shelving to 12 feet at the side of the channel furthest from Philadelphia. The total amount of material to be removed was estimated at 18 million cubic yards, portions of which were to be deposited in some of the shallower parts of the river, and the scheme also included the regulation and reconstruction of both banks of the river. Two islands in the proposed channel were to be entirely removed, as well as a portion of a third, and the harbour was to be generally improved. The work was undertaken by the American Dredging Company of Philadelphia, who employed from ten to fourteen dipper and grapple dredgers, seventy-five to ninety barges carrying from 250 cubic yards to 600 cubic yards each, three hydraulic dredgers, eighteen to twenty-five tugs, and from 300 to 400 men. So far, about 16,900,000 cubic yards have been removed, and the increase of depth obtained is stated by the Author to be in all cases permanent.

In the third section of the river only about one-half of the total length required improvement, and where the river-bottom was soft it was proposed to accomplish this by means of dykes directing the current so as to scour the channel, but where stone ledges occurred dredging was resorted to. Over this portion of the work, however, there is still a good deal to be done before the proposed depth of 26 feet at mean low-water over a minimum width of channel of 600 feet can be obtained throughout. The total length already improved is about 10 miles, of which only 4½ miles have been taken to the full depth of 26 feet.

The cost of the improvement of the second section of the river, Philadelphia harbour, was estimated at £700,000, and that of the third section at £485,000. The Paper is accompanied by two maps and two photographic views of the islands in the river opposite Philadelphia, taken before the work was commenced.

R. B. M.

The König Albert Harbour and New Railway Marshalling Yard at Dresden.

(Zeitschrift für Architektur und Ingenieurwesen, 1896, p. 145.)

This is an account of a visit of inspection made last October by the local authorities to these works completed a short time previously.

The area of the basins at low-water level is 14 hectares (34½ acres); the width of the entrance, from the Elbe, is 35 metres (115 feet). This area is sufficient to accommodate 300 of the

ordinary river-craft. The level of the bed of the basin is 3 metres (10 feet) below Elbe low-water level; the surface of the quays is 0·3 metre (1 foot) above the highest recorded Elbe flood-level, viz., that of March 31st, 1845. The length of the quayage is 2,300 metres (7,546 feet), and the height of the quay walls, inclusive of foundations, is 12 metres (40 feet), their thickness being 5·4 metres (17 feet 9 inches) at the ground-level. The earthwork was commenced 23rd June, 1891, the amount removed from the harbour basins being 1,520,000 cubic metres (1,991,200 cubic yards), and from the river channel 400,000 cubic metres (524,000 cubic yards). The masonry and concrete work was commenced 17th October, 1892, the cubical content of granite masonry and concrete together was 101,000 cubic metres (132,110 cubic yards). The quayage and basin of the winter harbour were brought into use in the autumn of 1894, and the commercial basin (*Verkehrshafen*) in the spring of 1896. At the up-stream end immediately adjacent, there is space suitable for the extension of the harbour, if needful hereafter.

The total cost of the harbour works was 7,450,000 marks (£372,500), of which 4,850,000 marks (£242,500) was for earth-work and masonry and 600,000 marks (£30,000) for sidings and sheds.

The new gravitation marshalling-yard, which is in the vicinity, is described. It is laid out practically in a similar manner to those in England where the idea originated. In this instance the plane is entirely artificial, being an embankment made up of the excavation obtained from the harbour works, and covers an area of 544,000 square metres (13½ acres), its greatest breadth being 400 metres (437 yards).

The length of sidings is 64,519 metres (40 miles). The method of marshalling is described. The works occupied three years in construction and were brought into use 1st May, 1894. The number of axles passing over the gridiron in twenty-four hours is about 9,000. In 1895 it amounted to 3,019,634, or half that number of vehicles. The cost of the works was about 7,900,000 marks (£395,000).

D. G.

The New Harbour on the Rhine at Düsseldorf.

(Deutsche Bauzeitung, 1896, p. 641.)

These works were opened 30th May, 1896, having occupied five years in construction and cost nearly 10 million marks (£500,000). They were much needed, as the former wharf arrangements were altogether out of date, and seriously restricted commercial development, as may be seen from the following figures. In the year 1855 the total incoming and outgoing tonnage of the Rhine harbours was, in millions, 1·1; in 1860 1·45; in 1870 3·93; in 1880 5·67; and in 1890 13·71. Of this

tonnage, Düsseldorf's share was in 1860 4 per cent.; in 1870 4·3 per cent.; in 1880 1·2 per cent., and lastly in 1890 only 0·9 per cent., although the town during this period had increased from 200 to 900 hectares (494 to 2,223 acres) in area, and from 60,000 to 176,000 in population.

The designs for the new works were got out and decided upon in 1889-90, and the works were soon after commenced. The Paper is illustrated by a small-scale map of the town and neighbourhood, a general plan of the harbour arrangement and a cross section through the Customs basin.

The harbour is situated at the south-western end of the town, where the river makes a sharp-curved bend, the eastern bank, or that next the harbour, being on the outside of the curve and consequently favourably situated as regards scour.

The arrangement comprises the Petroleum basin at the northern or down-stream end, which is entirely distinct from the rest of the arrangement, having its own separate entrance from the river. The remaining and main portion comprises the Customs, commercial, timber and refuge basins, and are all approached from a common entrance from the river.

On the eastern or inland side the harbour is bounded by the harbour station and its sidings, in connection with the Neuss-Düsseldorf Railway. On the west or side next the river, the harbour is bounded by a dam 3 metres (10 feet) broad at the top, and its crown 1 metre above the highest recorded flood-level, viz., that of 1822. The harbour entrance at summer water-level has a width of 70 metres (229 feet 8 inches), or 58 metres (190 feet 3 inches) at the level of the harbour bed, 4·30 metres (14 feet 1 inch) below summer-level. Immediately inside the entrance is an open water area of 185 to 240 metres (607 to 788 feet) in width, from which extend, right and left, the commercial and the Customs basins. These two, which are the opposite ends of one and the same basin, are bounded on the inland side by a shore wall, and the particulars of its method of construction are given in detail. The timber and refuge basins lie close to the preceding on the western side. The level of the harbour-bed is such as to permit of the largest Rhine vessels entering at the lowest known water-level, and there is a depth of 0·5 metre (1 foot 8 inches) in excess of that upon the Cologne-Emmerich section of the river.

The surface of the quays of the Petroleum, Customs and commercial basins is well above highest flood-level, but the top of tongue quays at the harbour entrance is only about the level of the highest navigable flood-level, which experience shows may be expected only once in seven years. The reason for this portion of the quays not being raised higher is for convenience in unloading.

The quays are laid with sidings connected with the harbour station-yard, where is a shed for four shunting locomotives. Altogether there are 18 kilometres (11·18 miles) of sidings, ninety-three points and crossings, and a turntable.

The total area of the harbour, including basins, quays, &c., is 79·75 hectares (197 acres); of this the basins occupy 22 hectares (54·3 acres). The structures include custom houses, railway offices, and those for machinery, including electric power and lighting plant. There are eight electric cranes from 1,500 to 4,000 kilograms (1·47 to 3·9 tons) lifting power, and a travelling crane of 1,500 kilograms (1·47 tons). A 25-ton crane is erected by a private company, and a grain elevator, costing 100,000 marks (£5,000), worked by electric power, is, or is about to be, erected. For lighting the harbour there are outside sixty-four arc-lamps, and for interior lighting twelve arc- and 847 glow-lamps.

The total cost of the works was 9,965,000 marks (£498,250): amongst the principal items being, land 1,571,000 marks (£78,550), earthwork 2,086,000 marks (£104,300), shore wall in customs and commercial basin 1,284,000 marks (£64,200).

D. G.

The Public Landing Stage of Pauillac. A. GASTON CORNÉ.

(*La Nature*, 6 March, 1897, p. 214.)

Bordeaux, which ranks as the third mercantile port in France, is situated 62 miles up the Gironde, measured from the open sea. The river is only navigable for vessels of large draught as far up as Pauillac, and hitherto it has been necessary for steamers of deep draught to discharge their passengers and the bulk of their cargo in mid-stream at Pauillac, in order to get up to Bordeaux at high tide. To obviate the difficulty caused by the want of suitable wharfage at Pauillac the works here described were put in hand and completed in 1895. By reference to a plan and a series of photographs an account is given of the undertaking, which was carried out from the designs of Mr. M. A. Roboglia. The pier is built on twenty rectangular masonry piles, with ninety-one intermediate cast-iron piles, each being driven down to the solid rock foundation by means of compressed air. These piles are tied together by cross-girders and support the massive oak staging forming the platform upon which the railway is constructed. There are eighteen hydraulic cranes of various sizes for loading and discharging purposes, and water is supplied from an artesian well sunk to a depth of 1,368 feet. Very considerable works have been executed on shore, comprising an embankment and a railway station, and railway lines have been laid on to the landing-stage.

G. R. R.

The Present Condition of the Inland Navigation of France.

A. DE BOVET.

(*Revue Générale des Sciences*, Paris, 1896, p. 820.)

Although the character of the traffic of inland navigation has been so much affected by the development of railways, insomuch that the conveyance of passengers is almost entirely monopolised by the latter, the importance of water-ways for the conveyance of merchandise, &c., is very considerable if not indeed as great as ever.

The routes followed by canals are those indicated as most favourable by the contours of the country traversed, and the same remark applies to railways, so that they are frequently practically parallel in their course, and the question, if dealt with by those concerned in a broad spirit, should lead to mutual benefit and development of traffic. Maps in the original show the conditions in the northern portion of France, where the exchange of traffic between the railways and the canals is very active, and the condition which exists in the south between Cete and Bordeaux where special circumstances have reduced it to nil.

The Paper is illustrated by maps of France, viz., Fig. 1, showing the navigable water-ways; Fig. 2 showing the same water-ways to a distorted scale, their width varying with the tonnage carried on the various sections in 1895, and the tonnage of the ports shown on the same map by proportional black patches. The third map, Fig. 3, shows the railways, the breadth of the lines representing their course being proportionate to the amount of traffic.

Table 1 gives the lengths of navigable rivers and canals, and the tonnage carried in 1890, their length being 12,323 kilometres (7,652 miles), and tonnage, ton-kilometres 25,504,330 (ton-miles 15,838,190).

A diagram of the traffic extending over the period 1847-1893 is given, the series of years plotted on the horizontal and the ton-kilometres on the vertical, showing the traffic upon the canals, the traffic upon the rivers, and their sum.

As regards the Loire it may be seen that the traffic on this river is practically nothing, the reason being that the navigation is so difficult and dangerous; but even if this be insuperable, there appears to be no reason why a parallel independent canal should not be worth making. The Rhone, as regards traffic, is not quite so low in the scale as the Loire, but it is much less than it should be considering its geographical position. In this case the principal reason for its being neglected is the velocity of the current.

A group of diagrams, Fig. 5, shows graphically the amount of tonnage divided under six heads, such as coal, materials for construction, timber, &c., upon six of the principal water-ways of France.

A chapter is devoted to a description of the various river and canal craft generally in use. The motor-vessel, generally, is distinct from the transport-vessel, and the Author considers that this is likely to prevail still more in the future, owing to the delays to which transport-vessels are always liable. In France the proportions of the combined motor- and transport-boat to the total number of inland navigation boats is 2·9 per cent, and these are mostly on the Rhône, where towing is almost impracticable.

On that river they vary from 120 to 135 metres (390 to 440 feet) in length, with a tonnage of 400 to 500 tons. Plans and sections are given of the various barges, &c., in use, and the question of the form of vessel with least resistance to towage is considered. The question of traction is dealt with, rivers and canals being treated separately, and the methods adopted on rivers, viz., towage by tug-boats and towage by hauling on a submerged cable, the latter method the more suitable for swift currents. The cost of traction in various instances is given.

D. G.

The Nira Irrigation Canal.

(The Engineer, 5 and 19 February, and 5 March, 1897, pp. 135 *&c. seq.*)

In years of famine the fall of rain in the eastern plain of the Bombay Deccan is deficient, and no water-supply, except that obtained from rivers rising in the ranges of the Western Ghaut Mountains, can be depended upon. Works, therefore, which store up a considerable portion of the discharge of these rivers at high levels, so as to command an extensive area of cultivable land, are the best protection against famine. With this idea, the course of the River Nira was examined, and it was found that a canal taken from a point in the river at Vir would command an area of 356 square miles of irrigable land. The scheme was sanctioned in 1881. It consisted of a weir across the Nira at Vir and a canal on the left bank of the river 101 miles long, discharging 455 cubic feet per second at its head, together with a great storage reservoir at Bhatghar, 19½ miles above the weir. The weir is built across the river at right angles, being 2,273 feet long, and the crest being 42 feet above the original bed of the river. It contains sluices for regulating the flow into the canal. Subsidiary weirs were constructed below the main weir so as to back up the water, to form a cushion to protect the rock foundation against the cascade of falling water during floods. The weir is built of rubble masonry and concrete, the hydraulic lime being formed from kunker. The canal has a mean fall of 0·96 foot per mile, the fall being greatest when the section is least; the velocities range from 1½ foot to 5 feet per second; where the fall in the country is great the drop in the inclination is made either by running a channel down a steep slope, or by vertical masonry drops of a

maximum height of 5 feet. The depressions are crossed by embankments, spurs are passed by deep cuttings, and the canal is carried over rivers by arches of 30 feet span. The distributaries lead from the main canal by outlets formed, for the smaller channels, by cast-iron pipes laid under the banks of the canal, with sluice-valves at the lower end, and for larger channels concrete culverts are built through the bank. It is assumed that 1 cubic foot per second will irrigate 100 acres, and that only half the irrigable area will be in cultivation at a time. The loss of water in the canal is about 1 cubic foot per second per mile in length.

A. W. B.

The Extensions to the Dunkirk Docks. A. DUMAS.

(Le Génie Civil, 12 and 19 December, 1896, pp. 81 and 97.)

The extensions, now nearly completed, of the port accommodation at Dunkirk are of a very comprehensive nature; they were authorised in 1879 at an estimated cost of £2,000,000, and include, in addition to a large new entrance lock and a floating dock, the deepening and widening of the entrance, a canal basin between the Mardyck Canal and the dock, two new dry docks and two new wet docks on the east of the entrance (not yet completed) as well as some minor improvements.

After an outline of the history of the port, the Author describes the present extensions. The new entrance lock has a width of 82 feet, a useful length of 558 feet, with a maximum depth of 35 feet 9 inches, and a minimum depth of 30 feet at high water. The total length is 687 feet 4 inches, and there are three pairs of ebb gates dividing the lock into two portions, 228 feet 8 inches and 350 feet 4 inches long respectively. The ends of the lock are designed for closing by means of caissons, when necessary for the examination and repair of the sills and gates. The emptying of the lock is effected by means of culverts 8 feet 10 inches wide and 11 feet 6 inches high, with "fan" sluices, in which the pressure on the main sluice is relieved by the pressure on the tail, which closes over a small by-pass culvert. The gates are of steel, each leaf being 45 feet 11 inches long and 39 feet 5 inches high; they have a double skin, with vertical frames and horizontal bracings, the pressure being transmitted to the heel and meeting posts through horizontal frames at the top and at sill-level. The gates are worked by hydraulic cylinders and chains, and brakes are provided to hold the gates against the inward impact of the waves. The foundations, which are of concrete, rest on 6,300 piles, averaging 12 inches in diameter, and from 14 feet 9 inches to 18 feet long, driven into a thick layer of sand. The concrete is formed of hydraulic lime mortar and trass, mixed with sand, broken brick, &c., and is nowhere less than 6 feet 6 inches thick. On the concrete is placed a layer of brick-

work, and on this again a facing of dressed stone forming the floor of the lock. The side walls are partly of brick and partly of masonry faced with dressed stone, and the sills, quoins, &c., are of Brittany or Normandy granite.

The new floating-dock contains four wet docks, from 260 feet to 330 feet wide, opening out of it, and altogether comprises 72 acres, the quay space being 79 acres, and the total length of quay about $3\frac{1}{2}$ miles. The deeper half of the dock has a depth of 32 feet 6 inches at high water of spring tides. The walls are of masonry faced with dressed stone, and stand on concrete. The first portions of the work carried out were entirely of concrete, with the exception of a dressed stone facing; but this construction was found to be unsatisfactory and had to be rebuilt, and the remainder was formed entirely of masonry.

One of the new dry docks is 317 feet 6 inches long over all, with a useful length of 227 feet; the width at quay-level is 63 feet 3 inches, and at sill-level 45 feet 11 inches. The other is 662 feet 6 inches over all, the useful length being 623 feet 3 inches, with a width at quay-level of 90 feet 3 inches, and at sill of 66 feet 11 inches. The entrance to the smaller dock has a depth of only 21 feet 2 inches; but those of the larger, which, in case of emergency, can also be used as an entrance lock to the wet dock, have a depth of 26 feet 3 inches at high water spring tides. The sides of the entrances have a batter of 3 to 1, and are closed by rectangular floating caissons fitting into grooves in the sides of the entrances, and manoeuvred by pumping water into or out of them as required. The capacity of the pumps for emptying the dry docks is such that the larger dock, containing 9,700,000 gallons, can be emptied in less than three hours. The engines driving the pumps are of 627 I.H.P.

Besides the deepening of the entrance, the improvements also included the reconstruction of the jetty forming one side of it, so as to widen the channel. The width thus gained was from 180 feet at the sea end to 360 feet opposite the new entrance lock, giving a total width of from 393 feet to 656 feet. The new jetty has a total length of 2,600 feet, 525 feet of which at the landward end is formed by a concrete and masonry breakwater, the remainder being of open timberwork on a masonry base, this latter being carried to varying heights to suit circumstances. The top of the jetty carries a footway 8 feet 10 inches wide, at a height of 10 feet 2 inches above high water. The masonry base rests on concrete, and here, as well as throughout the work, with the exception of the entrance lock, compressed air was largely used for putting in foundations.

The Author very fully describes various details of the work, and the article is illustrated by one single-page and one double-page plate of details, as well as by several smaller illustrations and views of the work in the body of the Paper.

R. B. M.

The Waterworks of the City of Basle. A. MARKUS.(Schweizerische Bauzeitung, October, 1896, p. 101 *et seq.* 11 Figs.)

The city of Basle bought up in the year 1875 the wells and waterworks constructed in 1866 by a limited company. The maximum delivery of water calculated from the size of the leading pipes is about 2,420,000 gallons per day, but at times the output varies very greatly.

It being desirable to increase the supply, two places were considered, Birsfelden on the left bank of the Rhine, and the left bank of the Wiese near the "Langen Erlen" in Klein Basle, and the latter source was finally selected.

The surface water flows out of the Wiesenthal through a layer of gravel resting upon the impervious schist and then sinks gradually to the Rhine. Borings showed that the gravel bed varied in thickness from 39.5 feet to 65.6 feet. In order to obtain reliable information on the amount of water to be obtained, a trial boring was made in 1878, and during a test of two weeks, pumping night and day, an output of 77,916 gallons per hour was obtained, with a depression of the natural water-level of 7.88 feet. At the same time, by means of observation-holes round the boring, it was found that the depression of the water-level did not extend more than about 273 yards.

The Author describes the plant which was put down in 1881, and gives details and dimensions. The pump-valves were originally of the Faroot type, but Etagen ring-valves were substituted, and the speed could be raised from 28 revolutions to 35 revolutions per minute, and the output to 2,310,000 gallons per day. The boilers are of the Ten Brink type, and all the plant was made by Messrs. Socin and Wick of Basle. The pressure service-pipe is not connected direct to the reservoir, but is directly connected to the town network.

In 1886 a second boring was sunk at a distance of 240 yards from the first. In the ten years from 1881 to 1891 the whole of the demand for water could be supplied; but after the later date it rapidly increased and greater pumping-power was needed. In 1892 the average daily consumption was 29.5 gallons per head, and the maximum 44.66 gallons. It was decided to calculate on an average demand per head per day of 35.2 gallons and a maximum of 50.6 gallons for the whole population, and it was considered this would suffice until the year 1910.

With a population of 120,000 inhabitants it would therefore be necessary to deliver a maximum output of 6,072,000 gallons, and, as only 572,000 gallons could be obtained from Grellingen, there remained 5,500,000 gallons to be supplied by the pumps, or a total of 66 gallons per second for a twenty-three hours' run; the present plant will give 22 gallons per second, and it was considered essential to sink four more wells, each capable of giving 11 gallons per second, and to supply two sets of pumps, each

capable of dealing with 22 gallons per second. In 1894 work was begun on two wells and one set of pumps.

One of these wells was sunk in forty-one days and the other in twenty-two days; work at the latter was carried on night and day, and the collecting well also required twenty-two days of twenty-four hours each. The boring itself was lined with iron cylinders, strengthened with timber struts, and at the bottom of the boring was fixed a conical wrought-iron tube, connected at its upper and smaller end to the vertical tube forming the actual well. The suction-pipe passed down the centre of the well. Besides the four wells there is also a collecting well already alluded to.

In the spring of 1895, with a ground-water level 3·28 feet below the average, 22 gallons per second were obtained from well No. 3, and 17·6 gallons per second from well No. 4. The collecting well is 13·2 feet in diameter, built of cement blocks resting on a concrete foundation; a description is given of the method of sinking.

Each of the wells is connected with the collecting well by a pipe 15·7 inches in diameter; ordinary flange or socket-pipes were avoided, and a special type with stuffing-box joints, packed with india-rubber, were used. The air is drawn out of the suction-pipes by a Korting-pump of Pelton type, fed off the high-pressure town mains.

The engine plant was calculated upon the assumption that 22 gallons per second had to be raised 296 feet, inclusive of friction loss. This is equal to 120 HP. in water lifted and with an efficiency of 80 per cent. an engine of 150 HP. was needed. Dowson gas was chosen as the motive power for several reasons. The gas-works are owned by the town and it is difficult to get rid of the coke; it was therefore decided to use coke only in the producers and to start the apparatus with illuminating gas. The Author then gives particulars of the Dowson gas-plant. There are three generators and two small boilers for producing steam; one generator and one steam-boiler are sufficient to produce all the gas required, and an analysis of the gas is given. The gas-engine is of the Deutz type, with a maximum output of 160 HP., and has one cylinder on each side of the crank-shaft with electric ignition. Starting is effected by a 10-HP. turbine fed with high-pressure water; the engine drives the three-throw pumps by means of cotton ropes.

The contractors guaranteed an output of 787,200 foot-lbs. per lb. of coke, and the mean result obtained was 902,000 foot-lbs. per lb.; these figures may be compared with those for the steam-engine, which were 623,200 foot-lbs. guaranteed per lb. and 652,207 foot-lbs. actually obtained per lb. of coke; the ordinary efficiency was, however, much lower. The generator plant and gas-engine were supplied by the Gasmotoren Fabrik Deutz. Tests made in April, 1896, showed better results still; 1·88 lb. of coke used per HP. of water lifted and an output of 1,028,280 foot-lbs. per lb. of coke used.

The total cost of the plant was £18,041.

E. R. D.

The Purification of Sewage Water by Filtration through Peat.

GEORG FRANK.

(Gesundheits-Ingenieur, 15 November, 1896, p. 345 *et seq.*)

The value of peat in a powdered condition as a means of increasing the manurial worth of human and other excreta is insisted upon. This is due principally to its ready absorption of liquids and gases. Various methods of using peat-dust in dry closets are discussed; but it is asserted that the employment of peat in this way will never become widely prevalent, owing to the general introduction of the water-carriage system. The amount of polluted water which comes to the sewers, though it varies considerably in different localities, may be assumed to be about 100 litres per head daily, and the problem which has to be solved is how best to render this dilute volume of sewage available for agriculture. Filtration through peat has been proposed by way of a solution; but hitherto this plan has not produced satisfactory results. The Author considers the reasons for previous non-success, and suggests that this failure is probably due to the air which is always present in finely-divided peat. In order to render peat available for use as a filtering material, and to expel the air, it must be reduced to a fine state of division under water, and be there brought to the condition of sludge. When this is done, and the peat-sludge is introduced into any kind of filtering apparatus, it proves to be a most excellent filtering material. Sundry tests of peat-filters were made in the laboratory with cultures of vibrios, and the colonies present in the filtered and unfiltered sewage were counted. It was found that in passing through the peat-filter the majority of the germs present were retained. Subsequently, at the Wiesbaden sewage works, some experiments upon a larger scale were carried out by the Author, who was able to demonstrate that peat prepared in the mode recommended by him was sufficiently porous to be used upon a commercial scale for sewage filtration. He proved, moreover, that the bulk of the impurities could be removed by this means from the sewage water, and that the resultant peat-sludge was possessed of considerable manurial value. The filtered effluent was sufficiently pure to be discharged into a river. The Author maintains that the dangers likely to arise from the supposed presence in the effluent water of pathogenic germs are of trifling importance.

G. R. R.

The Cost of Steam-Rolling on Roads. L. PIERRET.

(Annales des Ponts et Chaussées, August, 1896, p. 160.)

This is a short article in which the Author estimates the cost of working of steam-rollers. He considers three sizes of roller, and estimates the cost of working of each per ton of roller per mile run. The items of expense which are included are: (1) coal, water, oil, waste, &c.; (2) wages of the driver; (3) repairs; (4) interest and sinking fund on the original capital cost. The three sizes of roller considered were 12-ton, 16-ton, and 19-ton, and the costs of working per ton-mile were as follows:—

—	12-Ton Roller.	16-Ton Roller.	19-Ton Roller.
Coal, &c.	0·674	0·674	0·689
Wages	1·149	0·858	0·705
Repairs	0·567	0·567	0·552
Interest and sinking fund . . .	0·353	0·291	0·230
Total	2·743	2·390	2·176

The Author goes fully into the details of his figures, and considers that the first of these prices is approximately that paid for rolling by contract, when in addition the cost of moving the roller from place to place has to be paid. This last item is therefore saved when the roller belongs to the road authority, as the figures given above include all expenses over a long period, and the wages include idle days, while the ton-mile was taken in the work actually done in road-construction.

With the heavier rollers there is a still further economy, while at the same time there are also the several advantages resulting from independence from contractors.

The cost of road-material, labour in its distribution, watching, watering, &c., is not included in these estimates.

R. B. M.

*The Use of Gas for Domestic Lighting.*¹ Prof. VIVIAN B. LEWES.

(Industries and Iron, vol. xxii., 1897, pp. 47, 64, 85.)

In experiments made by the Author, it was found that Russian Solar Distillate—from Baku petroleum residuum—and the “blue” and “green” shale oils are the best for converting into gas, for

¹ Cantor Lecture, December 1896.

domestic lighting, in Pintsch, Patterson, or Pope generators. The most efficient working temperature is 900° C., and the best results attainable are 98 cubic feet of 50-candle gas per gallon of oil (20 per cent. of the original volume of the latter being left as residual benzene, paraffins and olefines). By the Young process of gas-making from shale oil, these residual products are eliminated, the oil-gas (prepared at between 800° and 900° C.) being washed by passage through the oil itself, so that only the fixed gases escape to the purifiers, and there is no residue, except about 28 per cent. of very hard coke left in the retort.

Oil-gas is, however, too rich to burn by itself, its illuminating power—fifty to sixty candles—being too great to be properly developed in the ordinary burner, and if the size of the burner be decreased, in order to secure the complete combustion of the gas, then the flame is cooled down by the atmospheric nitrogen to such an extent that the lighting capacity is seriously diminished. The process of manufacture is also too delicate and the apparatus too large to be suitable for ordinary domestic illumination.

Turning to acetylene, the Author has found by experiments on a practical scale that a mixture of 60 per cent. of lime and 40 of carbon will give, in a three and a half hours' run, with a 60 volt, 1,000 ampere current, about 1 cwt. of carbide, 89·2 per cent. pure, capable of yielding 5 cubic feet of acetylene per pound, the production of carbide being thus at the rate of 0·3 to 0·4 lb. per electric HP. per hour.

The differences in the actual value of commercial carbide are great, six samples of English make being found to yield from 4·84 to 5·52 feet of gas per lb.; whilst four samples of German make yielded between 2·43 and 3·82 feet, and three Swiss samples 4·38 to 4·60 feet per lb. English carbide gives a very pure gas, containing only some 2·3 per cent. of sulphuretted hydrogen, whilst with the continental article 6·9 per cent. of impurities is not uncommon, some portion consisting of the dangerous phosphuretted hydrogen (from the use of phosphatic lime).

A warning is needed against placing too much reliance on automatic generators, especially those with small gas-holding capacity, since the liberation of gas by no means ceases when the carbide is removed from contact with water, but is continued to some extent by the condensed water vaporised by the heat of the initial reaction, so that, unless the gas be drawn off, the holder may either "blow" or generate dangerously high pressures. There is also danger of the pipes becoming choked by tarry bodies from the polymerisation of the gas by heat, and risk of steam getting into the service pipes. For country houses it is therefore advisable to have a holder large enough to contain an evening's supply, and to use only enough carbide to fill the holder with gas. The dangers of acetylene are mainly due to impure carbide and improper apparatus, the gas being less poisonous than coal-gas,

and but slightly explosive under ordinary pressure. It is dangerous to attempt to liquefy the gas by the pressure produced in the generator, though when liquefied in a proper apparatus it can be stored in cylinders, and in this storage affords a useful form of supply for domestic lighting.

Owing to its richness the gas must be burnt in very small burners, and the contamination of the air is very much less than in the case of coal-gas, being, for a 48-candle illumination, only as 2·50 is to 7·9 — 13·4 (according to the kind of coal-gas burner). The Author has constructed an acetylene burner giving a 32- to 34-candle-light with a consumption of 1 cubic foot of gas per hour; but all the burners are liable to choke after being some time in use, owing to the deposition of polymerised liquid hydrocarbons in the fine slits, the result being that the flame becomes smoky. The only known remedy so far is to replace the burner by a new one.

The small size of the acetylene burner allows only about one-fifth of the amount of gas to escape as would be the case with an ordinary coal-gas burner, and as the rate of diffusion of the two gases is as 2 to 3, the danger of explosion from an accidental escape would be about equal, though the explosive limit of mixtures of acetylene and air has a wider range than those of air and coal-gas.

As an enricher of poor fuel gas there is a great future before acetylene when carbide can be produced at a low price, the Author having discovered a simple means of raising such gas to 20 candle-power by the aid of 10 per cent. of acetylene.

With regard to diluting acetylene with air for domestic illumination, whilst it is easy to obtain such a mixture burning well, the apparatus is always liable to get out of order and become a source of great danger. The Bunsen principle is safer, but requires a high pressure of gas, and the results are extremely variable. A probable solution of the difficulty may be sought in the use of mixed carbides of calcium and aluminium or calcium and manganese, which will yield gases similar in composition to coal-gas.

From comparative experiments made with Pintsch's gas and acetylene consumed at the rate of 1·8 and 1 cubic foot per hour respectively, the relative candle-power per foot was as 8·90 to 30·09, measured at an angle of 45°, with a view to use in railway carriages, thus showing the remarkable superiority of acetylene over oil-gas for this purpose.

C. S.

The State Railways of Saxony in 1895.

(Zeitschrift für Architektur und Ingenieurwesen, 1896, p. 192.)

By the opening of the normal gauge Reichenberg and Löbau-Weissenberg Railway, and the extension of the normal gauge Pockau-Olbernhau line to Neuhausen, the length of the Saxony State Railways at the end of 1895 amounted to 2,813·66 kilometres (1,747·3 miles). Of this length 2,764·46 kilometres (1,716·7 miles) was for passenger and goods traffic; 49·20 kilometres for goods traffic only; 829·92 kilometres (515·4 miles), or 29·49 per cent., was double line; 1,983·74 kilometres (1,231·9 miles), or 33·93 per cent., single line normal gauge; 701·68 kilometres (435·7 miles), or 24·94 per cent., normal gauge light lines; and 327·42 kilometres (203·3 miles), or 11·64 per cent., narrow gauge light lines.

Inclusive of the lines worked by private enterprise, of which 66·34 kilometres (41·2 miles) were for combined passenger and goods traffic, the total length of the railways in Saxony was 2,939·74 kilometres (1,825·6 miles). This, for the year in question, gives a length of 18·22 kilometres per 100 square kilometres (or 29·32 miles per 100 square miles).

Up to the end of 1892 there was expended by the State altogether 819,834,764 marks (£40,991,738), inclusive of 123,971,295 marks (£6,198,565) for rolling stock. The cost per kilometre averaged 294,623·74 marks (£14,731).

The rolling stock included 1,063 locomotives and 764 tenders, 2,802 passenger carriages, with seats for 109,730; 26,625 goods wagons of 251,000 tons weight, laden.

The total gross locomotive kilometrage was 28,513,547 (17,717,747 miles), or excluding running "light," 26,752,372 kilometres (16,623,924 miles).

There are a large number of other items given and compared with those of the preceding year, 1894, such as kilometrage of passenger carriages, goods wagons, average mileage per annum per passenger and per ton of goods, receipts per kilometre per passenger (3·10 pfennige or 0·372 penny) and per ton of goods (4·50 pfennige or 0·54 penny), gross receipts per kilometre per annum from passengers (11,190 marks or £900 per mile) and from goods (22,993 marks or £1,851 per mile), &c.

The average rate of dividend paid upon the capital was 4·52 per cent. as against 4·28 per cent. for the preceding year, 1894.

D. G.

Rapid Railway Construction.

(Le Génie Civil, 28 November, 1896, p. 53.)

When the great review of French troops took place at Chalons before the Czar, on the 9th October, 1896, the military authorities were in some difficulty as to the arrangements for the conveyance of spectators. The stands were about 3 miles from a railway station, and vehicles were scarce in the locality. At the last moment, on the 2nd October, it was decided to construct a short branch of railway from the Mourmelon station of the Compagnie de l'Est to the stands, and the same evening the 5th Regiment of Engineers, then at Versailles, received orders to construct it. The regiment arrived on the spot on the evening of the 3rd October, and the work was commenced on the morning of the 4th October at six o'clock. The whole of the line was completed and ballasted on the evening of the 8th October, and during that night the terminal station was decorated with poles and flags. All the permanent way materials were supplied by the Eastern Railway Company, who also sent 100 men, and these were employed on the ballasting and final levelling-up of the line. Five companies of railway engineers were also employed on the work from the morning of the 6th October, in addition to the 5th Regiment.

The works comprised $3\frac{1}{2}$ miles of line, with two sets of points and crossings, four road-level crossings, the ballasting of the whole of the line, requiring 1,300 cubic yards of ballast, over 1,200 yards of terminal platforms, water-tanks, buffer-stops, and $3\frac{3}{4}$ miles of telephone line. A small scale map shows the district through which the line runs. A great deal of rain fell during the construction of the work, but the traffic over the line on the 9th October was carried on without any sort of accident.

R. B. M.

The Glasgow District Railway.

(The Engineer, 4th December, 1896, p. 558.)

After two unsuccessful attempts to get their Bill through Parliament, the promoters, in 1890, obtained an Act to construct $6\frac{1}{2}$ miles of subway encircling the city. Its course is roughly an ellipse with major axis, east and west, about 2 miles, and minor axis about $1\frac{1}{2}$ mile; it crosses under the River Clyde twice, besides the various railways.

The line throughout is in tunnel, and consists of two cylindrical tubes each 11 feet in internal diameter and 2 feet 6 inches to 6 feet apart; the sharpest curves are 10 chains radius, and the steepest gradient, at the Clyde, is 1 in 20. There are fifteen stations, which are 28 feet wide and 150 feet long, with an island platform 10 feet in width, access thereto being gained by stairs

descending 20 feet to 30 feet. The strata encountered consisted of sand, clay, mud, shale and sandstone. Five different methods of working were adopted: (1) ordinary cut and cover; (2) underpinning under air-pressure, when the material drained only with difficulty; (3) iron tunnelling without air, where the strata was impervious and total immunity from subsidence was required; (4) ordinary brick tunnelling with impervious material and where the surface damage could be readily put right; (5) iron tunnelling with air-pressure through water-logged strata and at great depths. Where the tunnels were built of brick, the arch had from two to four rings and the sides two rings of brickwork; where built of concrete, the arch is 1 foot 6 inches thick and the invert 1 foot thick at the centre. The iron tunnels are built up of nine cast-iron segments 4 feet 1 $\frac{1}{2}$ inch by 1 foot 6 inches, with a key piece 9 inches by 1 foot 6 inches, completing the ring; the thickness varying from $\frac{3}{4}$ inch to 1 $\frac{1}{8}$ inch. Sixteen shields were used, 6 feet 6 inches long and built up of two plates each $\frac{1}{2}$ inch thick. They weighed 6 tons each, and were actuated by six hydraulic rams, working ordinarily with a pressure of 800 lbs. per square inch.

The trains are worked by a traction-cable in each tunnel, operated from a power-station in Scotland Street, containing two driving engines, with a total horse-power of 1,400. The cables are 1 $\frac{1}{2}$ inch diameter, and the speed of the cars is 15 to 16 $\frac{1}{2}$ miles per hour.

A. W. B.

Improvements on the New York Central Railway.

(*Scientific American*, 1897, p. 133.)

Until recently the New York Central Railway crossed the Harlem River on a two-line low-level swing-bridge, the approaches having four lines. These were laid on the level of the streets or in a cutting of varying depth. The inconvenience to the traffic on river, road and rail, caused by this condition of things had gradually increased, and it was necessary to raise the railway so much above its former level that the street traffic, having crossed over the cutting, now passes under the viaduct, and that all ordinary traffic on the river can now pass under the bridge and the latter is not opened so often as before. As no stoppage of traffic of any sort could be tolerated, expensive temporary structures had to be made, especially a temporary bridge and temporary timber frames spanning the four-line cutting on a length of several thousand feet, and supporting the central of the three longitudinal main girders until the old railway could be abandoned and columns could be placed under that girder.

The swing-bridge has two openings 100 feet clear each, and on one side of it are two spans of 185 feet and 131 feet respectively.

There are three main girders of the Pratt type, the centres of the outer girders being 58 feet 6 inches apart. Bridge and viaduct are covered with trough flooring laid crossways. The pier of the swing-bridge rests on 700 piles, their heads terminating in a bed of concrete upon which timber grillage 6½ feet thick was laid. The masonry built on the grillage consists of a central pier, six radial walls, and an outer ring carrying seventy-two rollers arranged in two concentric circles. The weight of the bridge, 2,500 tons, is brought by means of a system of longitudinal and cross-girders upon two drums, 46 feet and 56 feet diameter, and thus transmitted to the rollers while the central pivot carries no weight. Rack and pinion are the mechanism for turning the bridge. Steam engine and boiler are placed overhead between the girders. By a toggle-joint mechanism, driven from the engine house, 200 tons of the weight of the bridge can be transferred to the end piers. The cost of the steel viaduct was \$1,500,000, the cost of the bridge including foundations \$1,000,000, and the total cost of the undertaking \$3,200,000. The new work was opened for traffic on 15 February.

M. A. E.

Dynamometrical Tests on Express Compound Locomotives of the Paris-Lyons-Mediterranean Railway Company. PRIVAT.

(*Revue générale des Chemins de fer*, March, 1896, p. 152.)

The Author describes a series of tests which have been made on one of the latest express compound locomotives of the Paris-Lyons-Mediterranean Railway. The locomotive was the first of a series which was constructed in 1894-95 according to the plans of Mr. Bandry, and similar to those designed by him in 1892,¹ with a few important exceptions. The following are the principal dimensions :—

Weight of the engine, empty	46·73 tons.
" " " in service	49·80 "
Interior diameter of the boiler	4·33 feet.
Number of tubes	133
Length of tubes	9·84 feet.
Interior diameter of tubes	2·46 inches.
Heating surface of tubes	1,486 square feet.
" of fire-box	108 " "
Total heating surface	1,594 " "
Grate area	25·62 "
Diameter of high-pressure cylinders	13·39 inches.
" of low- " " "	21·26 "
Stroke of pistons	24·41 "
Diameter of driving-wheels	6·56 feet.
" of bogie	3·28 "
Wheel base	22·64 "
Total length of the engine	32·25 "
" width " " "	9·51 "

¹ Minutes of Proceedings Inst. C.E., vol. cxiii. p. 433.

PARIS TO LAROCHE DIRECTION.

	Notch of Introduction.	High-pressure Cylinder.	Low-pressure Cylinder.	Date of Journey (Train No. 1).	Tonnage of Train in Tons (Engines and Tender not included).	Time occupied on Journey.	Average Speed in Miles per Hour.	Average Effective Power measured on the Tendr Coupling.	Water Used During the Journey in Lbs.	Per Horse and per Hour in Lbs.	State of Atmosphere.
Variable	4	3/7/95	211·4	2 15 12	42 42·72	261·87	24,242	41·08	Fine, little wind.		
"	5	4/7/95	217·0	2 15 0	42·78	258·42	22,833	39·27	{ Fine, very little wind.		
"	6	5/7/95	211·4	2 14 36	42·91	249·54	20,968	37·46	{ Rain at intervals, little wind.		
"	7	6/7/95	208·8	2 14 54	42·80	261·38	21,832	37·14	Fine, little wind.		

LAROCHE TO PARIS DIRECTION.

	Notch of Introduction.	High-pressure Cylinder.	Low-pressure Cylinder.	Date of Journey (Train No. 8).	Tonnage of Train in Tons (Engines and Tender not included).	Time occupied on Journey.	Average Speed in Miles per Hour.	Average Effective Power measured on the Tendr Coupling.	Water Used During the Journey in Lbs.	Per Horse and per Hour in Lbs.	State of Atmosphere.
Variable	4	3/7/95	142·6	2 16 12	42·40	148·94	19,136	56·59	Fine, little wind.		
"	5	4/7/95	141·7	2 21 6	40·92	138·09	18,109	55·74	" " "		
"	6	5/7/95	141·3	2 20 24	41·13	153·87	17,921	49·77	" " "		
"	7	6/7/95	144·5	2 24 42	39·82	162·75	19,985	50·80	" " "		

The Author shows the relative value of the work, which he has sought to equalize in the high- and low-pressure cylinders with the new mechanism for reversing, which has been adopted by the Paris-Lyons-Mediterranean Company.

The Table below gives, for the 2, 3, 4, 5 notches of introduction to the high-pressure cylinders (the only ones used during the tests), and for speeds of about 50 miles per hour—

The average work per path T developed in the high-pressure cylinder.

" " " T' " " low " "

The relation $\frac{T}{T'}$ the average pressure p in the intermediate reservoir.

Notch of Introduction.		Value of T in Foot-Tons.	Value of T' in Foot-Tons.	Value of $\frac{T}{T'}$	Value of p in Lbs. per Square Inch.
High-pressure Cylinders.	Low-pressure Cylinders.				
2	7	19.07	3.42	5.57	12.8
3	7	22.43	7.18	3.13	22.8
4	7	25.79	11.22	2.30	29.9
5	7	26.75	15.77	1.69	41.2

Diagrams are given, taken with Deprez indicators, showing the forms taken in the above conditions. The new method of distribution adopted, in assuming that the maximum power of the locomotive is produced, tends to divide very nearly equally the work in the cylinders, when travelling at low speed, that is to say, with large introduction to the high-pressure cylinders, and to diminish progressively the proportional part of work allotted to the low-pressure cylinders in proportion as the speed increases, that is to say, as the introduction to the high-pressure cylinders diminishes.

In travelling at high speeds only a very small portion of the total work should be produced in the low-pressure cylinders, and the engine then acts almost as if the low-pressure cylinders were suppressed.

In addition to the Tables referred to, eight Plates are annexed, giving details of the locomotive tested, indicator diagrams, &c.

J. A. T.

The Chapsal Electro-Pneumatic Brake. FR. MIRON.

(L'Industrie Électrique, 1896, p. 551.)

The device, described in this article, is due to an official of the Western of France Railway, and is intended more especially to give the benefits of air-braking to long trains such as those carrying goods, &c. It is of course difficult under ordinary conditions to brake a long train of this kind simultaneously throughout its length, using any form of air-brake, whether vacuum or Westinghouse; but the Chapsal device is intended, by means of an electric circuit, to be combined with a Westinghouse-brake system so that the latter may come into action at the same instant the whole length of a train.

Two extra valves are required for each coach or wagon, one being used for throwing on the brake, the other for taking it off. A slight modification is also made to the triple valve, which is caused to act as an automatic commutating device. The driver's hand-lever for operating the brake has five positions, in one of which it is thrown out of action; in the others arranged for electric control, or pneumatic only.

At official experiments with the brake on a train of considerable length, a stop with the ordinary Westinghouse brake was made in five and a half seconds, whilst the same train equipped with the Chapsal control was stopped in two and a half seconds. No mention of the respective speeds is made, but presumably they were the same in both cases.

F. B. L.

Secondary Railways. C. DE BURLET.

(Zeitschrift für Transportwesen und Strassenbau, 1896, pp. 437 and 455.)

This is a report as to the advantages and disadvantages of laying secondary lines along the streets and upon independent planes. The Author treats the subject in considerable detail under the following heads: Cost of construction, traffic, conditions of construction, cost of maintenance, and working expenses. In the course of the discussion on the cost of maintenance, it is stated that in Belgium the railway company has to maintain the pavement between the rails, and a strip 60 centimetres (23·62 inches) on each side; but in the case of new pavement being required, the cost of the labour only is charged to the railway company, the materials being provided by the parish authorities. The Author arrives at the following conclusions: it is not possible to lay down any fixed rule as to which is the most advantageous method to employ in setting out secondary lines; each scheme requires individual consideration as to its local, topographical, technical, financial and other circumstances, which are summed up as follows: (a) Cost of construction. The purchase of land and construction of earthworks on the one hand, and on the other hand a permanent way which is generally very expensive; (b) Traffic, as to which will answer best for the collection of goods and which will procure the largest revenue; (c) The gradients, curves, &c., of the streets; (d) Cost of maintenance; on the one hand earthworks, bridges, &c., on the other hand repairs due to street traffic, falls of snow &c.; (e) Running expenses; (f) Local taxes and cost of land; (g) Rates of speed; (h) Disadvantages of street lines in regard to passing places, long trains, danger of accidents, &c.

J. A. T.

The Eaton Hall and Balderton Light Railway.

(Engineering, 20 November, 1896, p. 642.)

This is a 15-inch gauge line, and runs from Balderton Station on the Great Western Railway to Eaton Hall, the residence of the Duke of Westminster, a distance of 3 miles. There are also 1½ miles of branches. The railway is intended for mineral, goods, and passenger traffic. The rails weigh 16½ lbs. per yard, and are of the flat-bottom section. They rest on cast-iron sleepers weighing 28 lbs. each, and spaced 2 feet 3 inches apart. The rails are secured to jaws cast on the sleepers by steel spring keys. The line is ballasted by red furnace-cinder from 5 inches to 6 inches deep. The surface width is 4 feet. Through the park the railway formation is level with the turf, and special care is taken to build it so as not to be in any way conspicuous. The line is not fenced in, and cattle are prevented from going from one field to another by a trench, over which the rails are carried on girders with open decking. There are several bridges, the longest span being 28 feet; also two level crossings. The maximum gradient is 1 in 70, and the sharpest curve on the main line is of 300 feet radius. The rolling stock consists of one four-coupled locomotive, weighing 3 tons, and drawing on the level a maximum of 40 tons, excluding its own weight, or on the ruling gradient 20 tons; thirty wagons carrying 15 cwt. each; two wagons carrying 2 tons each; one passenger car to accommodate fifteen persons; a parcels van, and a brake van. The total cost of construction, excluding special storage-sheds, was £1,095 per mile, of which £205 per mile was for earthworks. The rolling stock cost £214 per mile, raising the total cost of the railway to £1,309 per mile. It is estimated that the working expenses amount to £250 per annum, and the interest and depreciation to £387 per annum; total £642 per annum. The estimated traffic at present is 5,000 tons of merchandise and minerals per annum, the cost of transport being about 1s. per ton-mile less than cartage. The line, however, is capable of dealing with double this traffic. The article is illustrated by two photographs of the termini.

A. P. H.

The Meckenbeuren-Tettnang Light Electric Railway.

P. GASNIER.

(L'Industrie Électrique, 1896, p. 397.)

The Meckenbeuren-Tettnang line is 4½ kilometres (2·88 miles), but the whole of it is on a grade, the latter being as much as 2 per cent. for half the total distance. The sharpest curve has a radius of 8½ chains. The line, as stated, is standard gauge, laid

with 44 lb. rails; there are fifteen turn-outs (the line itself being single track) and one cross-over.

A service of twenty-six trains at present suffices for the traffic, mixed passenger and goods cars running from the Meckenbeuren main line railway station along the electric line to the terminus at Tettnang, a town in Wurtemberg, near the Lake of Constance. The electricity is conveyed along the line by means of a trolley wire overhead; it is generated at a hydraulic power-house on the River Schussen, near Brochenzell, $1\frac{1}{2}$ kilometres (0.96 mile) from Meckenbeuren. The available fall of water is about 8 feet 6 inches, and the average quantity about 10,000 cubic feet per minute. Two Jonval turbines, respectively of 45 and 75 horse-power, are installed; these drive each end of a countershaft by means of rope gear, and a friction clutch on the latter permits the two to be coupled or separated as required. The electric generators—two in number—are driven by belts from the countershaft; one is wound for continuous currents, giving 43 kilowatts at 700 volts, of four-pole type, and employed for the railway. The other is a single-phase 40-kilowatt alternator, generating current at 2,100 volts for lighting and motive-power purposes at Tettnang.

In case the water-supply fails at Brochenzell, reserve steam plant is installed at Tettnang, consisting of a tubular boiler, a 60-HP. engine, and dynamo generators similar to those driven by the turbines. A feeder is run overhead for the whole length of line, being joined to the trolley wire at intervals of 220 yards; the rails are used as return circuit, giving an ohmic resistance not exceeding 0.01 ohm per kilometre (equal to about $\frac{1}{4}$ of an ohm per mile).

Two motor-cars only are employed, each equipped with two 25-HP. motors, and designed not only to carry passengers but having mail and baggage compartments also. The motors are always connected in series, and rheostatic control is used to regulate the speed. Each motor-car weighs about 7 tons; the wheel-base is 15 feet, and the motors are capable of a traction effort equal to 700 lbs. at 20 miles an hour, and 2,400 lbs. at 5 miles an hour. Goods trains of 55 tons weight are readily run at higher speeds, however, and the goods traffic generally has so much increased that a battery of accumulators is to be installed for utilizing the power station day and night if necessary.

The electric lighting both of Meckenbeuren and Tettnang is obtained through transformers placed in small brick and concrete "kiosks" provided with locked and bolted iron doors for inspection, the whole being mounted above ground and therefore thoroughly well drained. The low tension circuit (110 volts) is all overhead.

F. B. L.

On Elevated Railroads. J. A. L. WADDELL.

(Proceedings of the American Society of Civil Engineers, 1897, p. 1.)

The Author—when, as consulting engineer to the Chicago North Western and Lake Street Elevated Railroad, 1894, he collected data of metal work in existing elevated railroads—found much information “exemplifying how not to do it,” mainly in regard to the treatment of the live load and wind-pressure, also in regard to the designing of details of the parts and their connections, &c. He designed and estimated the cost of thirteen types of structure, all being illustrated in the Paper, and he discussed the details as to their respective strength and economy.

The design finally adopted for a four-line track has eight longitudinal-plate girders of 40 feet, or exceptionally, 47 feet and 50 feet span, supported by means of a cross-girder on four riveted steel columns which are anchored firmly to the foundation blocks. According to principles of economy, the cost of the longitudinal girders and platform should be the same as that of the cross-girders, columns and foundations together; this determines the span. Every 150 feet a span of 23 feet is braced longitudinally, and here an expansion joint is introduced. The transverse bracing between the columns is effected by means of brackets under the cross-girder. The cost of a four-track structure is about \$66 per lineal foot, and that of a two-track structure is half that amount.

The deficiency of design of leading details of existing elevated railroads is discussed at some length, and the Author concludes by giving illustrations of ornamental designing for the same railway in localities where it was made compulsory.

M. A. E.

Compressed Air-Motor on the Elevated Railroads, New York.

(Scientific American, 30 January, 1897, p. 72.)

This motor is intended to replace the steam locomotives now in use; the air is compressed to 2,000 lbs. per square inch in three stages, and the heat of compression is utilized by passing the heated air through the feed-water of the boilers at the compressing-station. The pressure is reduced to 150 lbs. at the cylinders of the motor. Before reaching the engine the air is re-heated by passing through a tank of water at 350°, which is carried on the motor and recharged at the end of each trip. During its passage through the hot water its volume is doubled by expansion and absorption of steam. The air is stored in tubes 9 inches diameter and 15½ feet long.

S. W. B.

A Single-Rail Railway.(Engineering, 5 and 12 February, 1897, p. 166 *et seq.*)

This system, which is the invention of Mr. Cailletet, is devised for those districts in which the smallness of the traffic will not justify even a Decauville railway. The track consists of a single flat-bottom rail weighing from 9 lbs. to 24 lbs. per yard, supported on flat sole-plates or sleepers, to which it is attached and by which it is fixed to the ground by pins. The rails are laid in sections, with sole-plates and fish-plates complete, in lengths of about 16 feet, weighing from 61 lbs. to 165 lbs. each. The rolling-stock is for the most part supported on four wheels in the same plane, with double flanges. Rods project sideways, by which the vehicles are at once propelled and kept in equilibrium, whether by manual- or horse-power. The load is distributed as evenly as possible on both sides of the centre line. Hinged supports can be let down, which render the vehicle stable during loading. The system is not intended for locomotive power. Numerous illustrations are given of various kinds of vehicles and methods of propulsion.

A. P. H.

The Protection of Level Crossings.

(Engineering, 5 February, 1897, p. 161.)

The Author discusses the various kinds of level crossings, and the regulations of the Board of Trade and the standing rules on most British railways with relation thereto. He concludes that double gates are better than single ones, when worked from a signal-cabin, and that rodding is preferable to chains. The self-acting stops should be locked or rendered inaccessible in populous districts. Wicket gates are much less convenient than bridges or subways approached by inclines. Where the former are used, they should be locked from the nearest signal-cabin on the approach of a train. The questions of stop signals on either side of level crossings, and of electric signals to gatekeepers working independently of any cabin, are fully discussed. All lamps on gates should have two red bulls-eyes, in order that if one lamp should be extinguished, the other may show in both directions. The use of treadles, worked by passing trains, is recommended as being more reliable than was formerly the case. The article concludes with some remarks on American practice.

A. P. H.

The Relative Values of Various Kinds of Permanent Way.

BLUM.

(Organ für die Fortschritte des Eisenbahnwesens, 1896, pp. 133 *et seq.*)

With the object of providing reliable data for the purpose of finding the best system of permanent way to adopt under varying conditions in view of safety and economy, the Author has collected a large amount of information from various railway companies, and has tabulated the result in a comprehensive Table, and in several graphic diagrams. Details are given for thirty-four different permanent-way arrangements, of which thirteen have steel sleepers, three have chairs on wooden sleepers, the remainder being flat-bottomed rails on wooden sleepers.

The Author compares in great detail the different results arrived at, and the following is a brief summary of his conclusions. The systems with stronger rails on lighter sleepers amount to about the same cost as weaker rails on stronger or more numerous sleepers, are superior as far as the rail-strain is concerned, but decidedly inferior in regard to the strain and deflection of the sleepers. In order to obtain the longest and most uniform life of all portions of the permanent way, either the strengthening of the sleepers or a simultaneous strengthening of both rails and sleepers appears to be the most suitable method to adopt. On lines where the price of sleepers is high, a decrease of the cost should not be obtained by shortening the sleepers or by decreasing the bearing surfaces, but rather by the adoption of half-round or trapezoidal sleepers with broad bearing-surfaces. Still less should the cost be diminished by the abolition of bed-plates. The most important consideration in every permanent-way strengthening is the nature and maintenance of the ballast, a good ballasting and formation reducing considerably the rail- and sleeper-strain, especially at the joints. The importance of the fish-plate joint is also emphasized, and the Author states that long fish-plates with a high moment of resistance are essential. The chair permanent way is dismissed by the Author as being much more costly, and offering no advantage in regard to strength in comparison with flat-bottomed rails with bed-plates.

J. A. T.

The Rail-Joint. FREUND.

(Revue générale des Chemins de fer, January, 1897, p. 3.)

The Author commences by describing the reasons of the different heights of rails at the joints—due either to inevitable imperfections in rolling or to unequal wear on the fishing surfaces—and gives enlarged diagrams showing the effect of the rolling load on passing over the rails, and illustrating how the wear of the fish-plates is

brought about. Several methods which have been tried with more or less success with a view to keep the rail-ends flush with each other are fully described, such as hoop-iron wedges on the fish-plates under the low rail, and a more elaborate application of this (as described by Mr. Ast, of Austria, at the London International Congress, 1895); continuous rails in course of trial in America; bridge or Fisher joints; the foot joints of Morgan, Stroudley, Thompson, and the St. Gotthard; oblique joints, scarf joints, auxiliary rail joints of various types; and, finally, a proposed half-joint with angular fish-plates, the length of the joint being about $2\frac{1}{2}$ inches. Plans and sections of all the above types are given.

In conclusion, the Author states that on existing lines the present means generally taken in maintaining the permanent way are insufficient for reducing the shocks and consequent wear and tear at the joints, and proposes the use of hoop-iron wedges carefully designed, and stronger fish-plates, and by this means he considers that the joints would bear the passage of about 500,000 trains under favourable conditions. For lines to be laid in the future he considers that a system should be adopted which will suppress as radically as possible the present inconveniences, and suggests either the half-joint or scarf joint as being capable of giving the best results; but before the adoption of either they should be subjected to severe tests and to the passage of at least 100,000 trains. The Author estimates the cost of the half-joint above the usual charges, and including the loss of length of rail, at 2 francs (= 1s. 7d.) per ton of rails.

J. A. T.

The Influence of Rails on Street Pavements. EDWARD P. NORTH.

(Proceedings of American Society of Civil Engineers, 1896, p. 579.)

An account is given of the various systems in use in American cities of laying lines of rails in paved streets. The Author states that the first rails used were so much of an improvement on the prevalent street pavements that the traffic early developed a tendency to follow the line of rails. In order to discourage this, as far as possible, the Hewitt or centre-bearing rail was devised; but its very brutality partially defeated its object, as a heavily-laden wagon could only be drawn off with difficulty, and it was fearfully obstructive to traffic crossing it at a sharp angle. By reference to a series of sections, the modifications from time to time proposed and adopted in the nature of side-bearing and grooved rails are explained and illustrated. A favourable opinion is expressed concerning a combination rail, consisting of two standard 60-lb. rails, with a cast-iron filler bolted between them. A portion of the head of the guard rail is planed off obliquely, and also the

projecting parts of the bottom flanges on the outer sides. This arrangement, it is said, gives a nearly perfect side-bearing to the paving-blocks, while the splayed groove between the rails enables ordinary vehicles to leave the track with ease. The Author states that while the section of rail adopted for most of the surface roads is obstructive to the rights and interests of the public, the style in which the space between the rails and between the tracks is maintained is often intentionally made much more obstructive. Some of the railway companies have thus appropriated a strip of the public thoroughfare 17 feet in width. The only remedy suggested is for the municipality to itself pave and keep in repair the portion of the roadway occupied by the rails and to charge the company with the cost of such works.

G. R. R.

Car Tracks and Pavements. JAMES OWEN.

(Proceedings of American Society of Civil Engineers, 1896, p. 587.)

The conditions under which the portion of the highway occupied by the tramway lines is maintained and repaired are reviewed, and the Author states that three different situations are possible:—

- (1) Where the municipality owns both track and street.
- (2) Where the company operating the railroad assumes, as part of its franchise, the care of the pavement in the street.
- (3) Where the municipality cares for the pavement outside the tracks, and the company cares for the track and the pavement between the rails.

The results arising under these various conditions are discussed. It is assumed, for the sake of argument, that every street railroad-track will, on the average, have to be renewed once in ten years. Certain special cases are considered, and the points which must be studied as respects construction and maintenance are noted. The question is also dealt with from the aspect of the requirements on suburban and country highways and macadam roads, and attention is drawn to the difficulties arising from the tendency of the traffic to become localized on parallel lines to the track. The Author states that, owing to the constantly increasing demand for good pavements and highways, the practice both of track and street maintenance is bound to receive more thought and care than it has in the past.

G. R. R.

An Electrical Shunting Locomotive.

(The Engineer, 12 February, 1897, p. 162.)

An electrical locomotive is in constant service at New Haven, U.S.A., for shunting freight-cars between the main line and a number of factories standing along the river front. The permanent way is of standard gauge laid with heavy steel rails, the sharpest curve being 50-feet radius and the steepest gradient 1 in 40. The locomotive weighs 26 tons and has four wheels; the frame is constructed of steel joists, and forms the foundation for a locomotive cab of sheet iron, with sloping shields at each end, which contains the automatic circuit breaker, controller, lightning arrester, reversing switch, and a dial ampere-meter reading up to 500 amperes. The controller is of the same general type as those used in ordinary street-car practice. The resistances are placed beneath the shields and are of the packed ribbon type. The motors are two in number, one for each axle; they are gearless and supported on spiral springs resting on the side frames of the locomotive. The armatures are of the ironclad type, and, with the commutators, are mounted upon sleeves through which the axles pass. The sleeves rest in bearings on the motor-frame. Two projecting arms from the sleeve fit into openings in iron plates loose upon the axles, and similar projections from the wheel enter the plates from the other side, so that the armatures revolve the wheels, the connection having ample elasticity.

Two oscillating air-pumps furnish air to two tanks beneath the cab and are automatic in action.

Electricity for the locomotive is furnished from an electrical power-station about the middle of its journey, the current being taken by a trolley from an overhead wire suspended from brackets.

The locomotive can handle seven heavily-loaded cars, about 200 tons weight, only 150 amperes being required to start it.

A. W. B.

Shunt-Motors for Railway Work. WM. BAXTER, Jun.

(Electrical World, 1896, p. 720.)

The almost entire possession of the electric railway and tramway field by series-wound motors, does not appear to the Author sufficient reason for the want of attention to the many advantages of shunt-motors for the same purpose; and he thinks that designers of electric-traction plant would do well to consider the various points at issue, with a view to using both types of machine.

The advantages of shunt-motors are by no means few or unimportant; they recover energy in descending grades and may therefore be used partly as brakes; they will give a greater

variation in speed, and any given torque can be obtained at several different velocities; the speed, moreover, can be increased or decreased without respect to the voltage.

They cannot, however, be made so substantial as series machines, in regard to the field coils; whilst their size, and, consequently, cost of construction are both greater.

Regulation of electromotive force is effected by commutating the field coils in various sections; several arrangements for doing this are shown diagrammatically. A diagram of the controller circuits is also given, and it merits comparison with the controller devices used with series motors if only on account of its much greater simplicity. The liability of sparking at points of breaking contact is also much reduced.

The Author deals fully with the best methods of constructing and arranging the fields, &c.; and concludes that shunt-wound motors may be made quite as efficient as series machines, if not actually more so.

F. B. L.

Rails for Tramways. C. LOOMIS ALLEN.

(The Electrical World, New York, 1896, vol. xxviii. p. 361.)

Rails of hard steel, the analysis of which shows a greater percentage of carbon than the standard specification of rail steel, are advocated by the Author as being especially suited to the heavy work now demanded from electrical tramways; and he gives as a desirable composition of steel the following percentages:—

Carbon, from	0·53 to 0·63
Phosphorus, not to exceed	0·095
Sulphur, " " " " "	0·07
Manganese	0·80 „ 1·00
Silicon	0·10 „ 0·12

From steel with these ingredients, the rails lately put down are in 60-foot lengths, 9 inches high, with half-groove section; the fish-plates are ribbed or corrugated, 36 inches long with twelve bolts.

F. B. L.

Thin Shafts rotating at High Speeds. L. KLEIN.

(Der Civilingenieur, 1895, col. 519.)

Professor Föppl has shown¹ mathematically that the deflection of a shaft in which the mass-centre has initially an eccentricity e increases with the speed of rotation, until a critical speed,

¹ Civilingenieur, 1895, p. 333; and Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 528.

n_o revolutions per minute, is reached, at which speed the deflection is $+\infty$, then changes to $-\infty$, and with further increase of speed the deflection remains negative, but its absolute value decreases. The deflection e at any speed, n revolutions per minute, is

$$e = \frac{n_o^2}{n_o^2 - n^2} e_o.$$

Since the formulas were deduced by making certain assumptions, it seemed desirable to investigate the subject experimentally, specially to see whether the formulas can be applied with a fair degree of accuracy.

Six shafts, of diameters 2·0, 2·2, 3·1, 3·4, 4·3 and 5·5 millimetres respectively, with loads 0·45, 0·55, 2·05, 3·05 and 10·05 kilograms respectively, were experimented on. Each weight was in the form of a small hand-wheel set eccentrically midway between the bearings, which were 28 centimetres apart. The critical speeds were respectively 553, 758, 1,095, 1,334, 1,265 and 2,460 revolutions per minute. Each shaft was run at speeds of 350, 612, 1,050, 1,800, 2,500, 4,400 and 7,500 revolutions per minute. In order to attain higher speeds than the critical, temporary bearings near the hand-wheel were used until the critical speed was considerably exceeded.

The experiments show conclusively that Föppl's formulas are perfectly reliable, especially as the initial eccentricity e_o will be much smaller in cases arising in ordinary practice than it was in these experiments. The deflections observed are given in tabular form, as well as the deflections calculated from the formulas; also the observed and calculated results are plotted in diagrams, which show at a glance the close agreement.

A. S.

Ropes and Rope-Driving. G. H. KENYON.

(Industries and Iron, vol. xxi., 1896, p. 15; vol. xxii., 1897, p. 7.)

The elasticity of rope is of great advantage in counter-balancing irregularities in the speed of the driving power and preventing shock and back-lashing. Complaints as to slipping, though frequent, are generally unfounded, as the absence of overheating at the surface of the pulley proves; neither do ropes cause any appreciable loss of power by wedging in the grooves, the excess of centrifugal force being so great as to prevent this tendency.

For the grooves the Author recommends those with straight sides inclined at an angle of 40°, and deep enough to prevent the rope reaching to the bottom curve. This shape keeps the rope from rolling, and helps it to wear down to fit the groove, thereby prolonging its life. The grooves on the driving and driven pulley should be turned to the same template.

As regards the relative size of pulleys and ropes, the best results are obtained when the ratio of diameters is 50 to 1 in the case of the smallest pulley, to minimise the fatiguing effect of alternate compression and extension on the rope.

For horizontal and down driving, back motion is the most effective, by preventing the wave-like motion (due to centrifugal force) which tends to throw the rope out of the grooves. There is a certain loss of frictional power which must be allowed for; but this, in upward driving, is checked by forcing the rope to run against the pulley instead of over it. In vertical driving the elasticity of the rope is the main factor governing efficiency.

Concerning the maximum length of unsupported ropes between centres, since ropes are found working well at 90 feet, this may be increased for back driving, provided the journals are well sustained, enough space allowed for the sag to run clear, and sufficient allowance is made for the extra weight of rope.

The advantages claimed for continuous driving are, in the Author's opinion, non-existent, the alleged equality of tension obtained by this system being a myth, whilst the increased liability to breakage—there being but a single splice—and the consequent stoppage of the machinery, constitutes a serious drawback, to which must be added the wear on the sides of the grooves, due to the rope entering at an angle—especially the last turn brought back across the full width of the pulley—and the effect of this wear on the rope itself.

Cross driving is also possible with ropes, but the pitch of the grooves should be double the ordinary distance, in order to minimise the effect of the ropes rubbing one against the other at the crossing points, and the ropes should be crossed in alternate ways to reduce their mutual friction.

In considering the question of thick (2-inch) *versus* thin ropes, it is pointed out that the percentage effect of any given amount of chafing is least in the former class of ropes, which are therefore more durable, although they are less frequently used than 1½-inch to 1¾-inch ropes, perhaps owing to the greater difficulty in splicing.

Guide-pulleys, whilst necessary for some classes of work, greatly reduce the life of the rope. Their effect in this direction may be lessened by using large, light pulleys, with deep, rounded grooves a little wider than the rope to be guided. In place of the small pulleys or rollers sometimes used to carry the rope around beams, &c., it is better to have an intermediate shaft and pulley, and drive forward.

Rope-driving also lends itself more readily to secondary motions than does belt-driving, the width of the driving-pulley being much smaller, and the traverse of the rope from loose to fast pulley being greatly reduced. For gradual starting, a shallow intermediate groove is turned in the fast pulley, enabling the rope to gain a turn or two before falling into the working groove.

As material for making driving-ropes, cotton is, up to the present, the best; manilla, Italian hemp, and similar fibres

lacking resiliency, and producing too much internal friction to give a long-lived driving-rope. Experiments have shown that, contrary to expectation, American cotton is better suited for the purpose than the finer Egyptian staple. In practice it is found that three-strand ropes wear the longest, there being much less internal friction and pinching than with those consisting of five and seven strands, besides having a higher breaking strain than any other form.

Splicing is an important factor in influencing the durability of a driving-rope, long splice equal to 72 diameters being preferable to the short or butt splice.

In lubricating ropes care should be taken to avoid greasy compounds which will clog the grooves and cause slipping. All that is really required is to rub the rope over lightly, about once a year, with a stiff mixture of graphite, tallow and soap, just to lay the broken fibres.

C. S.

Zinc Plates as Covering for Steam-Pipes. RUSSNER.

(Mittheilungen aus der Praxis des Dampfkessel- und Dampfmaschinen-Betriebes, 1896, p. 334.)

Peclet has shown that the heat radiated from a body depends on the state of its surface, the temperature difference between it and the surrounding bodies, and the temperature of the latter. If S be the heat radiated per square metre per hour, t_1 the temperature difference between the radiating body and its surroundings, t the temperature of the surrounding bodies, a a constant number, 1.0077, and K the coefficient of radiation for the surface in question—

$$S = 124 \cdot 72 K a^t (a^{t_1} - 1).$$

The values of K for a few materials are :—

Silver	0.18	Iron	3.17
Copper	0.16	Stone	3.60
Zinc	0.22	Wool	3.68
Tin	0.24	Oil	7.24

The Author found that a certain naked steam-pipe condensed 3.9 lbs. of steam per hour, while the same pipe, coated with tin-foil, condensed only 1.8 lbs. per hour. By using a mantle of zinc plate, leaving a layer of air between the pipe and its covering, the condensation can be still further reduced. Compared with the naked pipe, a covering of one zinc-plate mantle gave a saving of 83 per cent. of condensed water, a covering consisting of two mantles 86.6 per cent., while a felt covering 0.6 inch thick gave a saving of 91.4 per cent. The ordinary non-conducting coverings in use effect the following savings in condensed water :—Kieselguhr,

0·8—0·9 inch thick, 70 to 75 per cent.; cork fibre, 2 inches thick, 85 per cent.; soap-waste 1 inch thick, 85·6 per cent.

The Author points out that non-conducting compositions applied in a plastic state must be dried by heat supplied from the steam-pipe, and that the cost of this drying is generally overlooked by the owner. Further, owing to their greater thermal capacities, the cooling down losses at the end of each day are much greater for the plastic coverings than for zinc-plate coverings, so that at the end of a year the saving effected by the latter is not to be despised, while the zinc plate compares favourably with the plastic compositions in regard to first cost.

A. S.

Contribution to the Theory of the Gas-Engine. A. SLABY.

(Verhandlungen des Vereins zur Beförderung des Gewerbefleisses, 1896, p. 197.)

The Author discusses the cyclical changes that take place in the cylinder of an ideal gas-engine and of an actual gas-engine, and gives equations for the flow of heat from the gases to the cylinder-walls during each period of the cycle. For the complete cycle, the heat balance for the gases is expressed by the equation

$$Q = Q^e + Q^c + Q^w - Q^r + Q^m + Q^k,$$

and the heat balance for the cylinder-walls by the equation

$$Q^w - Q^r + Q^k = Q^{w_1} + Q^{w_2} + Q^{w_3} + Q^{w_4} - A(p_e - p_c) V_c;$$

where Q is the heat generated by combustion of the gases, Q^e the indicated work, Q^c the calorimetric exhaust waste, Q^w the jacket waste, Q^r the heat due to piston friction, Q^m the kinetic energy wasted at exhaust, Q^k the heat lost by radiation and conduction, Q^{w_1} , Q^{w_2} , Q^{w_3} , Q^{w_4} , the quantities of heat which flow from the gases to the cylinder-walls during the periods of charging, compression, expansion and exhaust respectively, P_e and P_c , the mean pressures during exhaust and charging respectively, and V_c the compression volume or clearance.

He then discusses the measurement of the quantities in the first of the above equations; the measurement of Q , Q^e , Q^c and Q^w presents no great difficulty, while that of Q^r , Q^m and Q^k does. He is of opinion that the piston friction depends on the mean temperature of the jacket water, and is little influenced by the temperature of the gases. If this be correct, the piston friction can be measured by closing the inlet and exhaust valves, driving the piston by another engine, and measuring the heat carried off by the jacket water.

Q^m is probably a function of the pressure of the gases at the moment of opening the exhaust-valve (P_e), and is best estimated as

a difference from the sum of the other expressions in the equations. In the Author's earlier experiments the values of Q^m seemed to vary irregularly, until he observed he had under-estimated the accumulator effect of the cylinder-walls. If during any trial the mean temperature of any portion has not attained a constant value, it is evident that the above equations are not exactly true. In some experiments he found that the engine had to run more than an hour before the cyclic changes were approximately steady. For the engine experimented on, he finds the law expressed by the following linear equation—

$$Q^m = 0.467 (p_i - p_o) - 0.354;$$

the pressures being expressed in atmospheres and Q^m in calories.

A. S.

*Tests of 200-kilowatt Continuous-current Parsons
Turbo-Generator.* W. D. HUNTER.

(Engineering, 19 February, 1897.)

This generator is designed to give a fair all-round economy, whether exhausting into the air or into a condenser, rather than to give a high efficiency under one set of conditions only. In the case of a 150-kilowatt generator exhausting into a condenser a steam consumption as low as 17.28 lbs. per E.H.P. per hour had previously been reached. In the generator under consideration the turbine was of the parallel-flow type, the steam admission being regulated by a sensitive electrical governor.

The results of trials were as follows:—

Method of Working.	Pounds of Water per E.H.P. per Hour at Full Load.
Non-condensing	32.22
Non-condensing and superheating 30° F.	30.97
Condensing, but no superheating	19.51

A. P. H.

"Climax" Water-Tube Boilers for the New York Steam Company.

(*Scientific American*, 30 January, 1897, p. 65.)

These very large boilers of 1,000 I.H.P. each are illustrated by photographs taken during erection. They form part of a plant for supplying steam for heating and power purposes to New York. The tubes are 3-inch diameter and barely $\frac{1}{8}$ inch in thickness. There is a central standpipe 5 feet in diameter and 38 $\frac{1}{2}$ feet high. Each tube leaves the standpipe radially, curves outwards and upwards and re-enters it 16 inches higher and one-third the circumference distant from the point at which it started. The external diameter of casing is 18 feet. The grate-surface is 160 square feet, and the heating-surface 10,000 square feet; 26 lbs. of coal are burned per hour per foot of grate, and 10 lbs. of water are evaporated per pound of coal from and at 212°.

S. W. B.

A Method of determining a Continuous Record of the Performance of a Marine Engine. Professor W. F. DURAND.

(*Journal of the American Society of Naval Engineers*, February, 1897, p. 1.)

The Author determines the relation between mean effective pressure and initial pressure and vacuum with a given engine by preliminary calibration trials. Maintaining a constant vacuum he takes cards at varying initial pressures and plots the values of the mean pressures obtained. He repeats the process with different amounts of vacuum. As the values so plotted fall in straight lines a few points only are required. On the trial of which a continuous record is to be obtained no cards are taken, but readings of steam-pressure, vacuum and revolutions are noted by an observer at quarter-minute intervals and afterwards plotted on a time basis. By means of the information obtained on the preliminary trial the power at any given period can be estimated from the values of steam-pressure, vacuum and revolutions, and a very close approximation to the true mean power developed during the whole time can be made.

S. W. B.

Pneumatic Grain Elevator.

(*Engineering*, 29 January, 1897, p. 151.)

This elevator was designed by Mr. Duckham, and is on the principle of pneumatic suction. The elevator is floating, and consists of a vessel 130 feet long, by 22 feet beam, by 11 feet deep.

The machinery comprises horizontal pneumatic engines, having steam-cylinders 22 inches and 42 inches diameter by 48 inches stroke, and four 38-inch diameter air-cylinders. Steam is supplied by two marine-type boilers. The air-pumps exhaust from two steel receivers raised 61 feet above water-level. The grain is drawn into these from the barges lying alongside through flexible suction-pipes, by which they can be completely emptied, without any cleaning up by hand, as is usual in the case of self-acting grabs or buckets. The grain flows from the receivers by gravity through rocking-boxes, each divided into two air-tight sections, one half being filled while the other is discharging. It falls thence on to trays which can be set to slope to port or starboard as may be desired, and which direct the grain into the delivery pipes. These in turn convey it to any part of the ship which is being loaded. The elevator is capable of dealing with 140 tons of grain per hour at low cost, the crew consisting of six men. The elevators are made in various sizes with capacities of from 10 tons to 200 tons per hour.

A. P. H.

*The Smelting of Mixed Zinc and Iron Ores at Bethlehem,
Pennsylvania.* JOSEF VON EHRENWERTH.

(Offizieller Bericht der k.k. oesterreichischen Central-Commission für der Welt
Ausstellung, Chicago, part vii. p. 90.)

The Franklinite ore of New Jersey is a variable mixture of minerals, the chief constituents being franklinite, willemite (silicate of zinc) and calcite, while as accessories in smaller quantities are found zincite (zinc oxide), tephroite, fowlerite (manganese silicates), garnet and a few other species, the average composition on the large scale being somewhat as follows:—

Mineral Constituents.		Specific Gravity.	Chemical Constituents.	
Mineral.	Per cent. of Ore.		Compounds.	Per cent.
Franklinite . . .	51·92	5·00—5·09	Fe ₂ O ₃	32·06
Willemite . . .	31·58	3·89—4·18	MnO	11·06
Calcite . . .	12·67	2·50—2·77	ZnO	29·35
Zincite . . .	0·52	5·43—5·70	CaCO ₃	12·67
Silicates . . .	3·31	4·00—4·12	SiO ₂ and acid	14·57
	100·00			99·71

The mixed ore as raised is passed through rock-breakers and roller crushers and sized through a sieve of $\frac{5}{8}$ inch mesh, the coarser stuff being passed through continuous jiggling machines, and the finer over endless cloth concentrators, the object being to remove

the lighter waste, *i.e.*, the calc spar. The mixed heavy minerals are forwarded to the smelting works of the Lehigh Zinc and Iron Company at South Bethlehem, Pennsylvania, where they are subjected to a preliminary series of operations in order to separate zinc ores proper, or those suitable for direct reduction, from those containing zinc, iron and manganese, which are utilized for zinc white and spiegeleisen manufacture. The rough ore is mixed with 20 per cent. by weight of anthracite, is subjected to partial reduction in a rotating cylindrical calciner about 30 feet long, with its axis inclined about four degrees towards the fire-box and heated by the flame from a group of Taylor gas-producers, the speed being so regulated that the mixture of ore and coal is at a bright red heat when it reaches the lower end of the cylinder, the ferric oxide constituent of the franklinite being reduced to the condition of magnetic oxide. The finished material is discharged continuously into a similar cylinder, but longer and of smaller diameter, placed below the calciner, and inclined in the opposite direction, whence it is delivered sufficiently cooled to go into the storage bin for the separators. The cooling is effected jointly by air passing over the heated material, which afterwards serves as a secondary supply in the combustion of the producer gas in the calciner, and by a continuous current of water which covers the outside of the cylinder over the greater part of its length. From the storage bin the roasted ore passes by a screw creeper to a bucket elevator which lifts it to a hopper above the magnetic separator containing an eight-mesh screen, which reduces the bulk of material to be treated by removing the greater part of the unburnt anthracite added in the first instance; while the siftings pass over the drums of three Wenstrom electro-magnetic separators arranged vertically one above the other, the magnetic portion separated going into the oxide-ore box, while the non-magnetic parts are collected in the zinc-ore box. The nature of the separation is seen by the following assay results:—

	Per cent.	Per cent.	Per cent.
Zinc ore.—Zinc . . .	46.38	Iron . . .	3.76
Oxide ore.—Zinc oxide 29.66	" . . .	37.20	Manganese . . .

The magnetic separator takes a current of 50 amperes at 75 to 80 volts, requiring about 20 HP., and has a capacity of about 40 tons of ore per day. The zinc ore is reduced in Belgian furnaces, and being free from lead and arsenic gives a high class of spelter known as the Sterling brand. The mixed ores are first heated for the removal of the zinc as oxide by the Wetherill process; the metal reduced by heating the ore mixed with anthracite in arch-roofed kilns with grated floors, is continuously volatilized and burnt by air blown in through the apertures in the grates, forming a dense cloud of zinc oxide which passes off with the furnace gases by a collecting main through several cooling chambers into a series of coarse cotton-cloth bags, where the oxide is finally separated by filtration from the gases which

escape through the meshes of the cloth. The oxide furnaces are rectangular in shape, the grates measuring 10 feet by 4 feet. The charge, from 5 to 7 inches deep on the grate, remains about six hours in the furnace, 83 per cent. of the total zinc being converted into oxide. The consumption of materials and products are as follows, per cent. on the ore treated :—

	Per cent.	Per cent.	Per cent.
Franklinite ore . . .	100·00	Best zinc, white (99·87 ZnO)	24·50
Reducing coal . . .	55·68	Impure (99·34)	1·50
Heating coal . . .	45·95	Residue	66·22

The residues containing in addition to iron, manganese and other non-volatile constituents, 17 per cent. of the total zinc in the original ore, are smelted for spiegeleisen in a small blast furnace, 42 feet high, 7 feet in diameter at the throat, 8 feet in the boshes and 6 feet in the hearth. The blast heated in a pipe stove to 900° F. is supplied by five tuyeres, four of 4-inch and one of 3-inch bore. The furnace top is closed with an ordinary cup-and-cone charger. The hearth walls are only 9 inches thick, but are protected by an outer water jacket extending 3 feet above the tuyeres, the duration of the lining being given at from eighteen to twenty years. The residues are fluxed with 53 per cent. of their weight of dolomitic limestone, and smelted with an equal weight of anthracite corresponding to about 42 cwt. of fuel per ton of metal produced. The latter is a high spiegel, containing manganese 14·96, silicon 0·412, and phosphorus 0·048 per cent. The daily make is about 10 tons, corresponding to 1 ton per 162 cubic feet of capacity. Owing to the large amount of zinc in the ore, it is not possible to use higher furnaces, as it is necessary to pass out the gases at a sufficiently high temperature to prevent zinc oxide from depositing in the throat flues and so choking the furnace, and even a less height, or about 34 feet, is better suited to ensure continuity in working. The gases pass by a comparatively large main to a group of vertical pipes arranged in four parallel series, forming an atmospheric condenser through which they are led up and down four times to free them from zinc. Afterwards they are burnt under the stoves and boilers in the usual way. The condenser is doubled, so that the working of the furnace need not be interrupted when it becomes necessary to clean out the deposit, which forms a yellowish brown mass, containing 74·16 per cent. of zinc oxide which is too impure for paint and is therefore sent to the spelter furnaces. The quantity collected amounts to 7·8 per cent. on the spiegel produced, or 2·32 per cent. of the original ore, making, together with 26 per cent. obtained in the oxide furnace, 28·32 per cent. out of the total of 29·66 per cent. of zinc oxide contained in the ore.

H. B.

Timber and Wood Consumption in the Comstock Mines.

W. ALVORD.

(Proceedings of the American Forestry Association, vol. x.; Engineering News, vol. xxxvi. p. 434.)

The details given by the Author of the amount and cost of timber used in the Comstock mines of Nevada afford a striking example of the enormous consumption of timber for mining purposes. From 1870 to 1891 there have been used for the mines and mills 674,765,000 feet of timber, and 391,070,500 cubic feet of wood, representing a total cost of £9,214,509. About 200,000 acres of forest have been destroyed to work the mines, and when the remaining 45,000 acres of forest are denuded, the timber-supply will have to be obtained at a distance of over 100 miles from the mines. Even now the bulk of the supply has to be transported 45 miles. The sizes of the timbers used vary from pieces 16 inches square and 24 feet long to smaller pieces 8 inches square used in cribbing. The species used consist to the extent of fully two-thirds of yellow pine (*Pinus ponderosa*), one-third of fir (*Picea magnifica*), and less than 1 per cent. of cedar (*Thuya gigantea*). None of the timbers have yet badly decayed, the heat and vapours of the mine appearing to have a preservative action. The area on which the forest has been destroyed is now being covered chiefly with pine, but it will require nearly a century for the trees to attain a size sufficient to furnish the timbers required by the mines. The present condition of the mines seems to indicate that the timber available will be adequate to their demands, but if new ore deposits should be discovered, an enormous expenditure must be incurred to supply the necessary timber.

B. H. B.

On the Composition of Fire-damp. By T. SCHLOESING.

(Annales des Mines, vol. xi., 1897, p. 5.)

At the suggestion of Mr. H. Le Chatelier, the Author has investigated the composition of fire-damp collected in a large number of collieries both in the northern and central coal-fields of France. In the samples examined the incombustible parts varied from 3·1 per cent. to 44·4 per cent. in volume, and contained carbonic acid (0 per cent. to 4 per cent.), oxygen (0 per cent. to 0·9 per cent.) and nitrogen (2·2 per cent. to 39·8 per cent.). The combustible part was essentially methane (CH_4), and gave results exactly similar to those obtained in the analyses of pure methane artificially prepared. Only three samples from Blanzy and Ronchamp were found to contain a denser hydro-carbon gas, ethane (C_2H_6) in proportions of 2 per cent. to 4 per cent. of that of the marsh gas.

Nitrogen is invariably present, but in very variable quantity, the limits observed being 0·74 per cent. and 30 per cent. In one instance as much as 40 per cent. was found in gas drawn from the solid coal at Blanzy, which the Author, however, thinks may have been partly due to intermixture with air. In all cases the nitrogen was found to contain argon varying in proportion from 0·74 per cent. to 3·28 per cent. of the total nitrogen and argon together, the lowest proportion being in gas from Ferminy and the highest from Anzin, the latter containing 18·1 per cent. of nitrogen. The gas from Rochebelle, which consists essentially of carbon dioxide, also contains argon in higher proportion than exists in the nitrogen of the air. Careful nitrogen determinations were also made upon the coal of Plat du Gier and Saint Etienne, the latter yielding 1·38 per cent. nitrogen by weight; but this was almost entirely free from argon or contained at most 1 part in 200,000. It is evident, therefore, that the argon in the fire-damp is not derived from the coal, but may probably represent fossil-air of the carboniferous period, either absorbed directly or carried in by water, in which argon is more soluble than nitrogen, and which would account for its being generally present in higher proportion than in the atmosphere. In one case, however, at Saint Etienne, the proportion, 1·18 per cent., was very close to that of the atmosphere, which is 1·19 per cent. of nitrogen and argon together.

H. B.

Magnetic Observations at Bochum in 1896. W. LENZ.

(Glückauf, vol. xxxiii., 1897, p. 257.)

Since the spring of 1895 the variation of the magnetic needle has been continuously recorded, by the aid of photography, at a magnetic observatory erected by the Westphalian colliery authorities at Bochum, and the results for 1896 are now published in tabular form. The tables, which cover thirteen pages, give the hourly value for every day in the year of the absolute declination, the daily amplitude or the difference between the greatest and least deviations, and, lastly, the character of the perturbations according to the classification introduced at the Royal Observatory at Potsdam.

Copies of the original curves are regularly forwarded to the mine surveyors of the district. According to the Potsdam method the curves are classified in the following manner:—

1. Very regular curves, showing at most very slight irregularities.
2. Curves of a fairly regular character with somewhat frequent small waves.
3. Slightly distorted curves, in which, although secondary waves of moderate amplitude and short duration (one to three hours) occur, the daily course is still clearly evident.

4. Fairly distorted curves, the course of which is appreciably affected by secondary waves of greater amplitude and longer duration (six to eight hours).

5. Curves with very large angular waves, occurring in great number and of long duration, and completely obscuring the normal course.

The earthquake felt in England in December had no effect on the declination needle at Dortmund. The greatest amplitude during the year was 48·3 minutes on December 4, and the least 2·2 minutes on December 8. The observations clearly show the great frequency of magnetic perturbations, and the necessity for mine surveyors making several observations underground on different days at one and the same time.

B. H. B.

On the Influence of Heat Treatment and Carbon upon the Solubility of Phosphorus in Steels. E. D. CAMPBELL and S. C. BABCOCK.

(American Chemical Journal; Industries and Iron, vol. xxi., 1896, p. 506.)

Three samples of steel: (1) Soft steel, with 0·1 per cent. carbon and 0·119 per cent. of phosphorus; (2) mild steel, with 0·37 per cent. carbon and 0·160 per cent. phosphorus; (3) Bessemer steel, with 0·78 per cent. carbon and 0·114 per cent. phosphorus, each of which was employed in three states, viz., normal, annealed, and hardened, were tested to determine the percentage of phosphorus soluble in mercuric chloride and the solubility of the residual phosphorus in 4 per cent. hydrochloric acid. From the table of results given, it appears that, where the percentage of carbon is small, heat has little effect on the solubility of the phosphorus (the total soluble being, in the hardened steel, 53·7, and in the other two 72·3 per cent. of the whole); but as the percentage of carbon increases, the solubility of the phosphorus is decreased by hardening (from 82·8 per cent. in the normal to 35·6 per cent. in the hardened steel), whilst with high percentages of carbon the solubility is increased by slow cooling (hardened, 27·1; normal, 78·9; annealed sample, 96·4 per cent. soluble).

These data indicate the probable formation at high temperatures of a compound of iron with carbon and phosphorus, soluble with difficulty, but convertible into a readily soluble form under the influence of gradual cooling; and the differences recorded might account, by the absorption or evolution of heat in the process of modification, for the retardation A_2 or A_3 (Osmond), similarly to the influence on recalescence of the conversion of carbon into cement-carbon.

C. S.

Melting Points of Aluminium, Silver, Gold, Copper and Platinum. S. W. HOLLMAN, R. R. LAWRENCE and L. BARR.

(*Philosophical Magazine*, vol. xli., 1896, p. 37.)

Assuming the melting point of gold to be $1,072^{\circ}$ C., according to the recent determination of Holborn and Wien, the Authors find the melting points of the other metals to be as follows: Al = 660° C., Ag = 970° C., Cu = $1,095^{\circ}$ C., Pt = $1,760^{\circ}$ C. The method consisted in measuring the electromotive force of a thermo-couple composed of platinum and an alloy of platinum with rhodium, one junction of which was kept in melting ice and the other immersed in the hot metal. The electromotive force was determined by balancing against a variable known potential difference according to Poggendorff's plan.

In the experiments on the melting point of platinum, the two wires were laid close together on a piece of lime, and one of them (the platinum) fused into a globule of an oxyhydrogen flame. No difficulty was found in obtaining sufficiently steady temperature in this way.

With aluminium a peculiar action occurred, the electromotive force of the thermo-junction falling off rapidly after a few minutes. The cause of this phenomenon was not satisfactorily ascertained.

G. J. B.

The Gölcher Secondary Cell.

(*Elektrotechnische Zeitschrift*, 1896, p. 675. 1 Fig.)

The Author points out that constant endeavours are being made to increase the capacity of the plates of secondary cells, as it is very important to be able to reduce the weight; the greatest possible surface should be exposed to the electrolyte, and the active material should be so fixed as to afford good contact with the plates, and not fall away. Mr. Gölcher has been working on the subject for two years, and has produced a new type of plate.

The novelty lies in the use of a special woven material instead of a lead grid as a frame for holding the active paste; this material consists of a warp of lead wire with a woof of very fine glass wool. After several yards of the material have been woven of the desired width in a special loom, it is cut into suitable lengths, the ends of the lead wire are bared, and the piece put in a mould and a stiff frame of lead run round it. The frame has the usual pair of lugs for support, and a projection for connection to other plates. The active material or paste is then put on to this web and worked among the threads, and the result is stated to be that it does not become loosened either by shaking or by the rapid

formation of gas. It is also stated that the plates do not buckle, as the elasticity of the glass wool allows of expansion.

Each plate is insulated from the adjoining plates by being bound round with glass wool. In this manner the space between plates is diminished to 0·12 inch, and the resistance is said to be somewhat lessened. The Author examined a cell containing eight positives and eight negatives (*sic*) in the Laboratory of the Gülicher Accumulator Works, Berlin, and this cell had a capacity of 120 ampere-hours for a discharge of twelve hours, and weighed, in working order, 23·54 lbs.; this is equal to 5 ampere-hours per lb. of cell. With a six-hours' discharge, the capacity is 100 ampere-hours. Details are given of the weights of the commercial sizes of plates made.

E. R. D.

On the Distribution of Oscillatory Discharges in Derived Circuits. LUIGI MAGRI.

(*Nuovo Cimento*, vol. iv., 1896, p. 321.)

Cardani, in his researches on the thermal phenomena of electrical discharges in derived circuits, did not take into account the character of the oscillations, nor the relative amount of self-induction in the various branches. The Author has investigated experimentally the distribution of oscillatory discharges of known period in parallel circuits of such form that their self-induction, singly and in combination, could be accurately determined. The method used was essentially that of Cardani. A Holtz machine, connected with a pair of condensers, was made to send a series of sparks through two coils joined in parallel. Each coil was enclosed in a species of thermometer filled with petroleum, the expansion of which served to measure the rise of temperature, and hence the heat evolved. In the first series of experiments the sparking distance was kept constant, and the capacity of the condensers and the self-induction of the coils were varied. In the second series the coils and condensers were kept constant in order that the effect of different sparking distances might be studied. The coils used were of such form that the ratio of self-induction to resistance was the same in each case, and it was found that their resistance to oscillatory discharges was independent of the oscillation period and of the potential of the discharges, being directly proportional to the length of wire. The resistance of such circuits is, therefore, within the limits of experimental error, directly proportional to their impedance, as is indicated by the formulas of Maxwell and Rayleigh.

G. J. B.

*A 600-kilowatt Hudin-Leblanc Flywheel Alternator.***ALIAMET.**

(L'Électricien, vol. xii., 1896, p. 353.)

Before describing this alternator the Author gives a few facts concerning the system of distribution in the Champs Élysées district in Paris. The alternate-current high-tension system at 3,000 volts and forty complete periods per second is employed. The transformers are placed in the consumers' houses, and reduce the pressure from 3,000 to 110 volts. It is found that, owing to the large number of transformers used, the power factor of the station at full load is only 80 per cent., and that this falls to 40 per cent. at light loads. The Author explains the inconvenience arising from the low power factor of the load; thus, the alternator at full load takes the current corresponding to 20 per cent. overload. Also the re-action of the armature is increased by the lag of the current behind the electromotive force.

The alternator in question is built up on the flywheel of a Corliss-Farcot engine running at sixty revolutions per minute. The diameter of the piston is 32 $\frac{1}{2}$ inches and the length of stroke 4 feet 7 inches. From the trials it was found that this engine, working with one-tenth cut-off, required 14.8 lbs. of steam per L.H.P. hour. It then indicated 600 HP. With a three-tenths cut-off the engine indicated 800 HP. and took 17 lbs. of steam per L.H.P.

The field-magnet system of the alternator is built up on the flywheel of this engine. It consists of eighty poles, each pair of adjacent poles being separately fixed to the rim of the wheel. The magnets are built up of sheet-iron. Each polar face is pierced by six holes in which are threaded copper bars of 0.82 square inch sectional area. These bars are riveted at their extremities into heavy copper segments which extend over the angular width of four poles. Their object is to prevent fluctuation of the magnetic field. The revolving magnets have a diameter of 19 feet 7 inches and a breadth at the polar surface of 25 inches. The direct current dynamo for exciting this machine also contains arrangements tending to prevent fluctuation in the exciting currents. The armature which is fixed consists of forty segments of laminated iron attached to a heavy cast-iron frame. Twelve rectangular holes are provided in each segment, only eight of which are used for the conductors. The winding consists of eighty coils divided into two series groups connected in parallel.

The wire used has a sectional area of 0.05 square inch, and there are twenty-four turns of it per bobbin, i.e., twelve per slot. Each segment containing two armature coils can be readily replaced. The Author gives the following figures for the energy lost in this alternator at full load.

	Watts.
Armature, copper loss	17,000
" hysteresis in foucaults	7,800
Magnet excitation	12,000
Losses in copper bars	6,500
Total	<u>42,800</u>

These losses are for a full-load current, but as the power factor is only 80 per cent. the output of the machine is 480 kilowatts. This gives an efficiency of 91·8 per cent. The Author gives characteristic curves of the machine on open circuit and short circuit, and also the electromotive-force curve.

The article is illustrated by sectional drawings and a general view of the plant.

R. W. W.

The First Cost of Transformers. GEORGE ADAMS.

(The Electrician, vol. xxxviii., 20 November, 1896, p. 112.)

The well-known formula $e_1 = 4 \cdot 45 Ft_1 n 10^{-8}$ and $e_2 = 4 \cdot 45 Ft_2 10^{-8}$, where e_1 = primary R.M.S. volts, e_2 = secondary R.M.S. volts, F = total flux in iron core, t_1 = primary turns, and t_2 = secondary turns, does not supply the data required in practice for designing a transformer. Generally the primary and secondary voltages, the frequency, and the output are given, and it remains to determine the best relation between the total flux in the iron core and the number of turns. For this no general rule can be given, as it depends partly on the size of the transformer and partly upon the kind of work for which it is intended. The Author has worked out the particulars of eleven different transformers, and gives the results in the form of a Table, showing the output, the primary and secondary turns, weight of copper and of iron with the cost of each, and the total cost per kilowatt, together with the primary and secondary currents, and the loss in the iron. He further shows how, by plotting some of the data in the form of curves, the number of turns corresponding to the lowest cost of materials can be ascertained.

G. J. B.

The Electric Power-Transmission Plant at Eichdorf Grünberg in Silesia. WALTER KLUG.

(Elektrotechnische Zeitschrift, 1896, p. 686. 9 Figs.)

The power-transmission plant at Grünberg, Silesia, is the second in Germany to use a potential of 10,000 volts. The energy is transmitted 15·5 miles by triphase current, and then transformed

down at various points in Grünberg to a suitable potential for use. Power is obtained from the River Bober on the site of the mills of the owner of the whole plant, Mr. H. Saalmann of Eichdorf, near Christianstadt, on the Bober. The water-power plant also drives the mill, and consists of an undershot water-wheel of about 90 HP. running at 8 revolutions per minute (*sic*), and this drives, by means of ropes, a shaft running at 175 revolutions per minute. There are also two turbines, giving together about 250 HP., which drive, through bevel wheels and then through belting, another shaft running at 500 revolutions per minute. From the low-speed shaft is driven, by belting, a three-phase machine of 80 HP. at 500 revolutions per minute, and from the high-speed shaft a machine of 220 HP. at 500 revolutions per minute by a friction coupling.

Besides this plant there is a triple expansion condensing steam-engine developing 300 HP., and a maximum of 374 HP. at a speed of 150 revolutions per minute, and coupled direct to a three-phase dynamo. All the polyphase machines are built to give 3×225 volts. at the station. Each is provided with its own direct coupled exciter giving 110 volts. The smallest machine is driven solely by water-power. The middle-sized machine can be driven either by water- or steam-power. At present the small machine takes the day load, and this and the middle machine together take the evening load. The steam generating plant consists of two water-tube boilers of the Gehre type. Each has 2,282 square feet of heating surface; the grates are specially designed for burning lignite. There are two 100-kilowatt and one 55-kilowatt transformers, and these raise the potential from 250 volts to 10,000 volts. The high tension leads are carried on poles to Grünberg, and have lightning arresters of the well-known V form. The overhead line runs along the main road between Eichdorf and Grünberg for almost the whole distance. The conductors consist of three copper wires, each having 0.054 square inch cross section, supported upon treble mantle insulators.

Two wires are placed at one side of the poles and one at the other, and there is a distance of 1.97 foot between any two wires. The poles are 45.93 feet high, the lowest wire being at least 29.53 feet above the roadway. By altering the relative position of the wires at regular distances, it is hoped to prevent induction in the telegraph wires on the other side of the road, 32.8 feet away. A telephone circuit of galvanised-iron wire with metallic return is run 3.28 feet below the high-tension wires to afford means of communication between the works and the office.

A barbed wire is carried along the tops of the poles, and acts as a lightning conductor; the line crosses several high roads, and where this is the case, special protection is afforded by means of wire-netting stretched below the high-tension wires. In the town the high-tension wires are insulated and carried to transformer stations; galvanised-steel wire-netting is used under the high-tension wires throughout the town, and where telephone wires cross

them netting is also carried from pole to pole above the wires, and several wires are stretched outside to afford protection at the sides. There are now in use seven transformers of 30 kilowatts and 50 kilowatts, and these reduce the potential from 10,000 to 120 volts. These transformers are placed in specially built iron turrets.

The distribution circuit is partly treble concentric armoured lead-covered cable laid in the ground, and partly overhead bare copper-wire on poles.

A test was made by the fire brigade in order to see the effect produced by sending a jet of water on to the high-tension leads. The nozzle was held only 3 feet away from the wires, and the jet played across two wires, while at the same time the gun-metal part of the hydrant was connected through an ampere meter to earth. The fuses did not melt, and no current was indicated on the ampere meter. The same experiment was repeated with 8,000 volts and with men holding the hydrant, and not the smallest shock was perceived. The Author describes in detail the elaborate precautions which are taken to switch off current from the high-potential overhead mains in the neighbourhood of a fire.

The work of installation was begun in April, 1895, and regular supply began February, 1896; in August, 1896, there were 4,300 16-candle-power glow-lamps and fifteen arc-lamps connected.

E. R. D.

Long Distance Power-Transmission.

(The Engineer, 5 March, 1897, p. 239.)

This scheme was to supply the town of Fresno, California, with heat, light and power. Fresno is situated in the valley of the San Joaquin river, and it has a population of 15,000. Power is obtained from the water of the San Joaquin river, 40 miles from the town, the working head being 1,411 feet. The minimum low-water flow will develop 7,000 HP.

The intake consists of a wooden flume run out into the stream, which passes into a canal contouring the hills for a distance of 7 miles. There is a waste-valve, for getting rid of flood-waters, every 4,000 feet. The canal has a capacity of 70 cubic feet per second and terminates in a reservoir holding several days' supply. The pipe-line starts from the reservoir down the mountain; its length is 4,020 feet, and consists of lock-jointed welded steel pipes from 20 inches to 24 inches diameter, and of a maximum thickness at the lower end of $\frac{1}{4}$ inch. The pipe is held to the rock by flat bands attached to anchor bolts. The pipe, being exposed, varied 8 inches in length with the temperature; the final connection was made early in the morning, and the pipe filled with water before the sun exerted much power.

It was found necessary to take at least half a minute to open the valves at the lower end of the line to prevent great fluctuations in the pressure. Jets of water $1\frac{1}{2}$ inch diameter, with a speed of 9,000 feet per minute, impinge on the buckets of Pelton wheels at an angle of 45° . These wheels are 57 inches diameter, having twenty-seven bronze buckets, and rotate at the rate of 600 revolutions per minute, developing 500 HP. Each wheel has a 60-inch diameter fly-wheel and works a dynamo. Step-up transformers raise the pressure to 11,200 volts for transmission.

A. W. B.

The Electricity Works at Jever in the Grand Duchy of Oldenburg.

(Elektrotechnische Zeitschrift, 1896, p. 629. 7 Figs.)

Jever is a little town of 5,500 inhabitants in an agricultural district with few factories. It was decided in 1895 to substitute electric lighting for petroleum lamps. Mr. Jordan, director of the municipal electricity works of Bremen, acted as consulting engineer. The contract was let to the Schuckert Company on the 24th August, 1895, and the supply of current began four months after, on the 20th December, 1895. The steam-boilers and engines consist of two Cornish boilers, one boiler being sufficient to supply the two engines. The latter are of the same size, compound horizontal type with jet condenser, and at 160 revolutions develop 60 HP. Condensation water is obtained from a small lake in the neighbourhood. The dynamos are of the four-pole type, belt-driven, and each develops 40 kilowatts at 700 revolutions; at this speed 220 volts to 240 volts can be obtained for direct lighting or 300 volts for battery charging. A Hagen accumulator is employed, consisting of 130 cells of a capacity of 500 ampere-hours, with charging current of 160 amperes and 90 ampere discharge (*sic*); with one dynamo and the battery 1,360 16-candle-power lamps can be fed, which corresponds to about 2,700 lamps connected.

The three-wire system is used, and the third wire is connected to the centre of the battery. The distribution is effected by overhead wires; a pair of feeders is carried to each of five points. At each point is fixed a tower consisting of a trellis mast and closed base containing the connections from the feeders to the three-wire system. The ordinary poles are of wood with insulators and are spaced 65·6 feet apart. The street lighting consists of 170 glow-lamps of 25 candle-power and ten arc-lamps of 8 amperes. The number of house connections seven months after opening was 120, besides thirty demands; these will have 2,000 glow-lamps, twelve arcs and six motors of from 1 HP. to 3 HP. The total therefore is equivalent to 2,250 16-candle-power for private consumers and 350 16-candle-power for public lighting, making

2,600 in all. The income from consumers in the first quarter of 1896 was £20, which was more than could be expected, as only forty houses were ready for connection when the station opened in December, and the remaining eighty have only come on gradually.

E. R. D.

Electricity Works at Niagara Falls.

(The Engineer, 11 December, 1896, p. 586.)

Power from Niagara Falls was received at Buffalo on the 16th November, 1896, transmitted by electricity over a line 26 miles long, 1,000 HP. being at present available, and additional power will be added as required. The two-phase system was selected for the generation and distribution of power in the vicinity of Niagara, but it was found to be too costly for transmitting to a distance; for this purpose the three-phase system was chosen. The capacity of the first line being fixed at 5,000 HP. at 11,000 volts, and 10,000 HP. at 22,000 volts. The line-poles are of shaved cedar painted white, from 35 feet to 65 feet in height, and 60 feet to 75 feet apart. They are sunk 6 feet to 8 feet in the ground, in clayey material; the filling round them is well punned, and in soft ground they are packed round with concrete. Double poles with cross-arms are used at sharp angles. Each single pole carries three cross-arms, the two upper ones for the transmission wires, and the lower for a telephone wire. The line consists of three conductors of bare copper, each conductor being a 19-strand cable, weighing 5,200 lbs. per mile; they are strung on porcelain insulators weighing 12 lbs. each.

Complete transposition of the wires is effected every 5 miles. The current begins at the 5,000-HP.-generators in the power-station at Niagara, whence it issues two-phase at 2,200 volts. The portion for Buffalo is led in lead-covered cables to the step-up transformers, which are of the air-blast type, of 1,250 HP. each; they change the current to a three-phase one, and raise the pressure to 11,000 volts or 22,000 volts as desired. At Buffalo, by means of step-down transformers, the current is reduced from 10,700 volts, or 21,400 volts, to 370 volts. The three-phase 370-volt alternating current is carried to rotary converters, which are six-pole machines, and is changed into a direct current of 500 volts for connection to the feeder lines of the tram company.

A. W. B.

The Electricity Works of Paris.¹ J. LAFFARGUE.

(L'Industrie Electrique, 1896, p. 463.)

In this article the Author gives a full tabulated statement of the seven divisions or "secteurs" into which Paris has been separated for the purposes of electrical distribution; and a map is also appended showing the areas supplied in this way. Six out of the seven areas are in the hands of private companies, the Halles Centrales district being the only one supplied from a municipal station. The Compagnie Continentale Edison operate in the northern section, where they have three electricity works and one sub-station; the Place Clichy Company take the next area on the west, with one large power-house; the north-east parts of Paris are lighted from no less than seven centres, all in the hands of one company. The Compressed Air (Popp) Company operate the eastern area from two high-tension alternating-current stations with two sub-stations; also three low-tension direct-current stations, also with two sub-stations. The Champs Élysées district, on the west of the city, is lighted from one large high-tension alternating-current station on the banks of the Seine, outside the City boundary—as is also the case with the station supplying the whole of the left-bank districts.

The following Table contains some of the chief particulars worth noting in regard to the capacity and development of the electric-light industry in Paris; it applies to the month of October, 1896:—

Total available output, in kilowatts, from generators	17,775
Ditto from accumulators	1,610
Number of arc-lamps installed	7,448
Number of glow-lamps installed	417,468
Equivalent of above reduced to 10-candle-power lamps	545,914
Equivalent of lamps installed, in kilowatts	21,844
Capacity in Kilowatts.	
Number of motors installed for miscellaneous power} purposes	293 858
Number of motors used for lifts, &c.	220 574
Total	<u>1,432</u>
Heating appliances, capacity in kilowatts	6
Total kilowatts installed—lighting, power and heating	29,278
Ratio of kilowatts installed to kilowatts in stations	1·309

The average charge for electricity during the year is stated to have been not less than 12 centimes per hectowatt-hour, equivalent to nearly 1s. per unit, but this high price is expected to be reduced to 8d. or 10d. in the early future.

F. B. L.

¹ Minutes of Proceedings Inst. C.E., vol. cxxv. p. 500.

Electric Street Lamps in the Avenue de l'Opéra, Paris.

(L'Industrie Électrique, 1896, p. 543.)

Although one of the most important and imposing streets in Paris, the Avenue de l'Opéra has only within the past few months been lighted by electricity according to modern methods, after a long interval of gas lighting, since the Jablochkoff lamps were removed.

The present application of electricity to the public lights on this important thoroughfare possesses considerable interest since the current is supplied from an alternating source—an arrangement not usually adopted for the purpose. Moreover, instead of operating the lamps in series of thirty or forty, using high pressure direct in the lamp-mains (as at Rome), the lamps required for the Avenue (fifty in number) are divided up into ten circuits, giving only five lamps in each circuit or series. They may therefore be operated on the ordinary 220-volt system, thus:—

	Volts.
Five lamps, each taking about 36 volts	180
Loss of pressure in leads	20
Choking coil, loss of pressure in	20
	<hr/>
	220
	<hr/>

One choking coil is used in each circuit, at the point of departure from the mains.

The lamps used are of the Kremenczky type, chosen after elaborate tests; they are differentially wound, with a brake feed operated by a double solenoid, and take 14 amperes each; the lower carbons being of 15 millimetres diameter, solid, whilst the upper ones are cored and 16 millimetres in diameter. It is claimed that such a combination ought to, and in practice does, give excellent illumination—a result not always easily obtained with alternate-current lamps.

The supply of current is taken at 2,400 volts from the Halles Centrales municipal station, a couple of transformers serving to reduce the pressure to 220 volts. Two are employed, as the lamps are divided into all-night lights and those extinguished at 1.30 A.M. They are installed, with a special switchboard, in a "kiosk" above-ground, in the Avenue itself.

F. B. L.

The Nice Electric-Lighting Station.

(L'Industrie Electrique, 1896, p. 439.)

The total output of the Nice electricity works is not great, only about 850 HP., but there are elements of interest and importance in the design of plant, &c., which make this detailed account of the entire installation worthy of reference.

In the first place, direct-coupled steam units only are employed, even for such comparatively small sizes as 150 HP. There are three installed each of this output normally, though capable for short periods of working up to 200 HP. each; the engines are compounded, with equilibrium piston valves, and run at a speed of 220 revolutions per minute. One large steam unit of 300 HP. is also used: the engine is of Corliss type with a single cylinder, running at 70 to 75 revolutions per minute, and worked with simple expansion non-condensing.

All the generators are of the same type, having four interior poles, and brushes bearing directly upon the armature bars, and are designed to give 110 and 200 kilowatts respectively at a pressure of 220 volts for operating the system by means of three wires.

Volt-raisers, or "boosters," are also provided for regulating the voltage in the ordinary way, with the help of batteries. The latter have an output equal to 600 ampere-hours. The arms of the three-wire system are balanced by means of a transformer or rotary converter, whose armatures are connected across each arm respectively, the field being excited by the full voltage. The generators are simple shunt-wound machines. The volt-raiser has only one motor-armature to drive the two generator-armatures.

F. B. L.

Electric Power and Light Installation in the Workshops and Stations at Gleiowitz.

(Elektrotechnische Zeitschrift, 1896, p. 742. 8 Figs.)

Tenders were invited in the spring of 1894 by the Royal Breslau Railway for the installation of electric light and power for their workshops and passenger and goods stations, and Messrs. Naglo Brothers obtained the contract. It is worthy of note as being the first State railway in which electricity alone is employed for production of power and light. The line is lighted for a distance of $2\frac{1}{2}$ miles, and there are 172 arc-lamps of 8 amperes to 13 amperes, 454 glow-lamps of 16 candle-power and 25 candle-power, and 60 electric motors of 0.5 HP. to 6 HP., with a total output of 150 HP. Work began in the spring of 1895, and was completed in October of the same year. Provision is made in the

central station for plant of 1,000 HP., and at present there are two dynamos direct-driven by steam-engines each of 250 HP., and one similar set of 150 HP. Steam at 150 lbs. pressure is supplied by three water-tube boilers. Dimensions and other data are given of the boilers, engines and dynamos. The smallest dynamo can be run at a higher speed if desired for occasional battery charging. The engines are of the non-condensing type, and the large ones used at full load 19·36 lbs. of steam per L.H.P. per hour, and the smaller one 19·8 lbs. The dynamos are of the eight-pole type, with external ring armatures formed as commutators outside.

The switchboard is of marble, 29·52 feet long.

The three-wire system is used, with 220 volts across the outside wires, and a balance is kept by a battery consisting of 120 Tudor cells with a capacity of 868 ampere-hours. The ordinary charging of the battery is effected by an auxiliary dynamo driven by a motor, while a duplicate motor and dynamo are kept in reserve.

In the workshop a potential of 110 volts is used for motors of 0·5 HP. to 2 HP., and 220 volts for the larger sizes; all are excited by current at 110 volts.

Of the sixty motors four of 6 HP. each are on overhead travellers and one of 3 HP. on a crane; current is carried to them by bare silicon-bronze wire.

Details are given of the special machines driven by each of the other fifty-five motors; these vary from $\frac{1}{2}$ HP. to 5 HP. Transmission from the motor to the machine is by belt, spur-gear or worm-gear; the spur-gear is of raw hide. An electric trolley-locomotive will shortly be used in the works. Full details of the lighting are given.

E. R. D.

The Electricity Works of Rathausen, near Lucerne.

Professor ET. GUINAND.

(Elektrotechnische Zeitschrift, 1897, p. 115. 16 Figs.)

The water-power plant of Rathausen, near Lucerne, is on the Reuss, about 1 mile below the junction with that river of the Emme.

The turbine-house has five chambers each for a reaction turbine of 300 HP. at 60 revolutions per minute, and a sixth chamber for a 6-HP. turbine at 270 revolutions for working the sluices and a drinking-water pump. Between the vaults of the turbine chambers and the floor of the dynamo-room there is a vaulted chamber in which are placed the bearings of the dynamo and turbine shafts, &c.

The useful fall is 15·8 feet at low water and 18·5 feet at high water, and gives, with a flow of 880 cubic feet per second, 1,200 B.H.P., and with 1,120 cubic feet per second, 1,500 B.H.P.

Work was begun in November, 1894, and completed in June,

1896. At present only three turbines, each of 300 HP., and one of 6 HP. are installed. The speed regulator is automatic and of entirely new design. The electrical part of the work is on the two-phase alternating system. The field magnets of the dynamo are fixed on the vertical shafts of the turbines and revolve inside stationary armatures.

The potential produced in the eighty bobbins of single-phase is 3,300 volts at 60 revolutions per minute, and the frequency is 40 per second. The exciter is a four-pole machine developing 70 volts and having an output of 15 HP.; each of these exciters is driven by gearing off the turbine-shaft which drives the dynamo it serves. The dynamos have an efficiency at full load of 90 per cent., and the main switch-board is designed for five such units as the three now in use.

Twenty-four bare high-tension leads leave the station and are carried to a tower 54 feet high and distributed thence by overhead lines. About 500 HP. is used at the Moos Ironworks for power transmission.

Lighting is carried out at 120 volts and the motors are worked at 250 volts, except those over 60 HP., which are worked off the high-tension mains direct. About 983 HP. is taken off for motor work.

E. R. D.

Electric Elevators. FRANK J. SPRAGUE.

(Transactions of the American Institute of Electrical Engineers, 1896, p. 8.)

In showing the importance of elevator work in modern times, the Author states that in New York city alone there are not less than 5,000 of these appliances in one form or another, and "more persons are carried vertically than horizontally." He proceeds to classify electric elevator services somewhat as follows:—

1. High speed passenger service, where want of space forbids the use of hydraulic gear.
2. High speed passenger service competing with hydraulic plants, but—in the Author's estimation—costing less and occupying less space, whilst doing the same duty.
3. Passenger service, with light loads.
4. Passenger service in private houses, where safety, simplicity and noiselessness are essential.
5. Goods and special services.

The first two of these may be called "first class," requiring speeds of from 300 to 600 feet a minute: the remainder are "second class," involving speeds of from 50 to 250 feet a minute. The latter service may usually be dealt with best by means of a drum hoisting machine, similar in general principles and design to the worm gear drum operated hitherto by steam-, gas- or oil-engines. The more important high-speed service can best be

given by an endless screw arrangement worked by the electric motor, and provided with a travelling nut and multiplying ropes; this corresponds to the most improved type of hydraulic elevator. Several illustrations with detailed description of the Author's designs for such an elevator are given, and the claims are made for the device that for high lifts it occupies less space, is more flexible in application, more cheaply worked and supervised, than the hydraulic elevators, whilst it has equal speed, safety and capacity.

The screw machine works on the gravity principle in descending; the drum machine is over-counterweighted, the excess being equal to the average live load. Therefore the total load, either up or down, is sometimes against the hoisting gear and sometimes with it.

The chief novelties about the screw machine are to be found in the crosshead and travelling nut, where a chain of balls takes up the bearing stress between nut and screw. These balls circulate in the nut round the screw, returning through a longitudinal ball-race cut in the base of the nut. One half of the rope multiplying is done at the machine, the ropes, properly proportioned, going thence to the bottom of the counterweight frame which has a single multiplying sheave on top. The car-ropes go over the shaft sheaves, under the counterweight multiplier and back up the hoistway where they are anchored, thus giving a car-speed twice that of the counterweight.

In the discussion upon this Paper, a great number of facts and figures relating to elevator work were brought forward, and the Author's opinions and conclusions were strongly combated. The general tendency of experience seemed to point out that though possessed of many admitted advantages, electric elevators were not in actual working any more economical than equally modern types of hydraulic or steam elevators, especially under circumstances—in the latter case—which allowed of the same plant being used for lifting as for heating.

F. B. L.

Automatic Starting- and Stopping-Gear for Electric Lifts.

C. SPEISER.

(Elektrotechnische Zeitschrift, 1896, p. 643. 5 Figs.)

The Schuckert Electricity Company has recently supplied a large number of both passenger and goods lifts; a special automatic starting and stopping gear is used.

In 1891 the firm, in conjunction with Messrs. Schelter and Giesecke of Leipzig, supplied the first electric lift. It was direct coupled to the motor on the same base-plate, with a drum driven by worm gear, and the brake gear was coupled to the reversing

gear. The old apparatus, however, was controlled by the usual rope, and necessitated the employment of a trained attendant, as a careless use of the rope caused sparking and destruction of the contacts. The business in electric lifts has greatly increased, owing to the low price of electricity from municipal stations, and the demand for a cheap and safe form of lift has also increased. An automatic apparatus is necessary to make the lift as independent of the care of the attendant as the hydraulic lift is, and two types of this apparatus are made, one chiefly used for goods lifts, travelling slowly, and the other for passengers. In the former type the resistance in circuit with the motor is gradually switched in and out by a small electric motor fixed to the upper surface of the apparatus. This acts by means of a worm and wheel and magnetic coupling. Switching on of the small motor, and of the magnetic coupling, takes place by turning a switch lever connected with the controlling rope. The resistance in the circuit of the lift motor is thus gradually taken out, and it starts slowly and gets up to its full speed; when that is reached, the auxiliary motor is automatically switched out again.

The same action takes place in the reverse order when it is required to stop the lift. The attendant thus controls only the auxiliary motor, which, in its turn, governs the lift motor. It is stated that an apparatus of this kind, lifting 5,500 lbs. and developing 12 HP., has been working satisfactorily for twelve months in the works of the makers.

The second type differs from that already described, as it has no auxiliary motor, and the switch and starting contacts are both on the same switchboard. The contact-lever, working upon a horizontal pivot, is not directly connected with the guide-rope, but with a piece having a certain amount of backlash. The automatic turning of the contact-lever is caused by a magnetic coupling connected by a worm and wheel and belt gearing to the lift motor. The starting of the motor is performed as follows:—

The contact-lever is pulled by means of the guide-rope against a stop, and the motor receives just enough current to start it; then the magnetic coupling comes into play and gradually cuts out the resistance. Illustrations in the original show the arrangement of the various parts. Several lifts are referred to, of which the most important appears to be one in the Nuremberg Exhibition, which is built for five persons, or a load of 660 lbs., and has a lift of 72 feet at a speed of 2·3 feet per second. This has carried 35,000 persons in three months.

The Author considers it desirable to provide electric lifts with a mechanism such as is now used with hydraulic lifts, so that automatic stopping at each floor can be effected, and thus the necessity for having a special attendant in the lift may be avoided.

A diagram of such an arrangement is given.

E. R. D.

Increasing the Efficiency of Electrical-Railway Motors. WILLIAM
BAXTER, Jun.

(Electrical World, New York, vol. xxviii., 1896, p. 559.)

In the early days of electric traction, the limits of space, due to size of car-wheel employed (30 inches diameter) and small height of car-floor above ground-level, forbade the use of anything but a double-reduction gear, especially as car-velocity did not, under ordinary circumstances, exceed 6 or 8 miles an hour. To avoid the serious repairs and waste involved by the double gearing, single-reduction motors were next devised; but these were extremely heavy and cumbersome, whilst for equal currents the torque was no more, but often less than with the double-reduction machines. Moreover, the car-wheel diameter had to be increased to 33 inches, and the car-body raised several inches, the clearance being at least 31 inches instead of 27 inches as before. The more modern type of single-reduction motor has been greatly reduced in weight since it does not now exceed say 1,500 lbs., but the car-wheels remain the same size, and the average consumption of current has in no way decreased, the idea being apparently to save unnecessary weight in the motor. Such a course is justified by some engineers, who say that current is the cheapest thing about an electric railway plant, though the use of highly economical steam-engines and generators so persistently aimed at rather contradicts this.

The Author's object in writing this Paper is to make suggestions whereby the current required for ordinary single-reduction motors may be considerably decreased, whilst at the same time maintaining most of the other improvements so far developed. He gives curves which show that the increase in horizontal effort with rising currents is not as proportionally great as it should be; this indicates that the field cross-section ought to be more to obtain the necessary flux with a low magnetizing force; also that the deficiency is made up by an increase in the ampere turns. He then goes on to show that although increase of cross-section in the proposed way with a reduced magnetizing force would cause the speed to drop with increase of current, yet this element of maintaining the speed is only secured at a very heavy expenditure of current, and does not really amount to much. As a matter of fact, the same result may be obtained with much less current.

A Table of current, horizontal effort, speed, power, and efficiency values is given with curved diagrams to prove and illustrate the position thus taken by the Author, who concludes that it is not a wise course to so reduce the field cross-section in order to obtain higher velocity with larger efforts, since the current consumption is thereby very considerably increased without any counterbalancing advantages. High-speed motors, even with large field cross-section, are not the best for roads where there is much stopping and starting; and if desired for interurban roads, they should be designed for low magnetizing force, and a

sufficiently small number of armature turns to obtain the required velocity, with a field of as large cross-section as can be obtained conveniently.

F. B. L.

Series-Parallel Controller for Four-Motor Equipments.

WILLIAM BAXTER, Jun.

(Electrical World, New York, vol. xxviii., 1896, p. 77.)

The extensive use of electric traction for heavy railroad service where large outputs are demanded, and consequently the employment of several powerful electric motors on each motor-car, has led to the design of special methods and apparatus for controlling and regulating these, somewhat after the fashion already well known in tramway work with double-motor equipments.

The essential differences or additions to the ordinary controller mechanism consist of a commutating switch and rheostats, the reversing switches being also of a slightly more complicated nature. The Author traces out in this article the various combinations possible, a diagram with terminal and wire connections serving to illustrate these. With four motors it is, of course, obvious that their respective inter-arrangement alone will give a substantial variation in working—that is, the four motors may be coupled, first, all in series; next, two parallels with two in series; or two series with two in parallels; and, last, all four in parallel. The commutating switch has two positions, corresponding to a slow and a fast combination respectively. When in the first-named the motors either are arranged all in series or in two parallels with two in series. Changing over to the fast combination, the motors are then coupled up in two series with two in parallel or all four in parallel. There are twelve contacts under the "slow combination," ranging from all resistance in circuit (in parallel) with the four motors in series to all resistance out of circuit with the motors in two parallel groups, No. 1 in series with No. 3, No. 2 in series with No. 4. The motor fields are not shunted at all when using the slow combination. After tracing out the combinations resulting from the different contacts when running slow, the Author does the same in detail for the "fast combination," varying from (position 1) motors Nos. 1 and 3, in parallel with the branch currents passing through them, meeting at a contact and then passing through motors Nos. 2 and 4, also in parallel with one another, up to (position 12), all the motor fields shunted with the armatures in parallel, which represents the highest speed obtainable.

It will be seen from this that the devices herein described are fundamentally the same as those already used for double-motor equipments, although considerably extended and complicated by the employment of additional motors and resistances. A great range of variation in output is, however, possible, with corresponding economy of working.

F. B. L.

Inspection of Trolley-Car Equipments. JAMES B. CAHOON.

(The Electrical World, New York, vol. xxviii., 1896, p. 336.)

In strong contradistinction to the custom hitherto too prevalent of allowing electric trolley-car equipments to run until serious breakdowns occur, the Author in this communication advises constant care and inspection of the motors and gear generally, there being in his opinion at least three different species of over-haul which every car ought to undergo.

The first of these consists of a more or less cursory examination after each journey by the motor man, to see that the axleboxes are all right, with no signs of heating; that the grease cups are filled; the motors in good order externally and electrically so far as is shown by working conditions; also that the brakes act properly. This examination is no more than would be carried out by any locomotive driver at each important stopping-place, and it should be emulated by the trolley-car motor man.

The second inspection should take place at the end of each day's work when the cars are taken into the depot, and here there should be two inspectors ready to mount the car, prepared with bellows to blow dust from motor armatures and fields; also to wipe the commutators, examine and renew brushes if necessary, carefully try all the electrical connections, and the various nuts, bolts, &c., both in the motor gear and brake mechanism. The car is afterwards washed, swept and dusted in the usual way.

The third inspection, of a more comprehensive kind, should be made at least once a month, when the cars are taken over the pits and the motors dropped down, taken apart and thoroughly cleaned; gears, pinions and brasses are removed if they will not last another month, the armatures and fields are carefully cleaned and painted, and the commutators turned down if necessary. At the same time both the truck and car-body receive equally careful attention.

The Author has found that brake shoes with sections of hard metal cast in them last much longer than the ordinary homogeneous cast-iron shoe.

F. B. L.

Corrosion caused by Railway Return-Currents.

DUGALD C. JACKSON.

(The Electrical World, New York, vol. xxviii., 1896, p. 684.)

In this article the Author details the results of a series of experiments undertaken to ascertain the differences in chemical reactions with lead and iron respectively as anodes on which corrosion occurs when a current passes under conditions such as prevail in the ground with electric railway return circuits.

Tables are given summarizing the results, and stating the weight of metal lost in a given time, &c.; and the conclusions reached by the Author are briefly as follows:—

(1) Corrosion of the anode is due to secondary reactions caused by the electrolysis of certain salts held in solution in the soil, and not by direct oxidation from the electrolysis of water.

(2) Corrosion takes place wherever a current is leaving the pipe or conductor, however small the difference of potential; and the rate at which metal is removed depends solely upon the strength of the current and the nature of the salts in the soil.

(3) A very small quantity of a salt in solution is sufficient to start the corrosion when a current flows, and the action continues as long as the current flows.

(4) Corrosion will occur with the smallest possible difference of potential, provided the earth's resistance permits any current to flow.

F. B. L.

Electric Disturbances from Tramway Conductors.

PAUL VAN VLOOTEN.

(Proceedings of the International Union of Tramways, 1896.)

The International Union of Tramways recently sent circular inquiries to the various electric tramway engineers in Europe, asking for information on the disturbances noted by them in the telephone and telegraphic services and underground pipes due to the tramway conductors. The Author has prepared from the replies received a report for the Union on the subject, and on the best means to prevent such harmful effects. The questions were asked under three headings, i.e. (a) faults due to contacts between the tramway wires and other conductors, (b) disturbances due to induction, (c) electrolytic action on the surrounding system of pipes in the ground. The Author concludes that the first trouble of accidental contact and leakages from one circuit to another can be easily guarded against. The disturbances due to induction are more general and difficult to diminish. The fluctuation in the current due to commutation sets up in the telephonic circuits a note corresponding to the number of sections in the commutator passed by the brush per second. Hence as large a number of sections as possible should be used. Another serious set of oscillations in the current is set up owing to the variation in the resistance of the circuit at the collecting trolley, and between the wheels of the car and the rails. These contacts should be kept as good as possible and all vibration of the track should be avoided. The Author quotes several of the replies sent in contrasting the behaviour in this respect of the various forms of collectors. He then proceeds to summarise the various guard-wires, earthing devices and fuses used to prevent the high voltage tramway current doing harm to

a telephonic circuit should accidental contact between them be made. The Author then discusses the telephonic circuit and summarises the following facts. Earth-return telephonic circuits are most strongly affected. Earths obtained for telephone-circuits near the tramways augment the effects. Induction is the greatest cause of the noise heard, and a metallic return with the conductors twisted round each other on the poles prevents this almost entirely. Putting the telephone-conductors in iron pipes under ground protects them from disturbing influences. The Author then gives extracts of Mr. Justice Kekewich's judgment in the case of The National Telephone Company Limited *v.* Gruff Baker, and comments on the same. The question of electrolytic action is treated at length. The Author advises the reduction of the resistance of the return circuit as much as possible by binding the rails and also by providing return-feeders on the earth side. The judicious selection of the site in respect to the length of lines to be served facilitates the solution of the difficulty.

The use of three-phase alternate currents as at Lugano does away with all electrolytic action.

R. W. W.

Special Non-exchangeable Cut-outs.

(Elektrotechnische Zeitschrift, 1896, p. 447. 2 Figs.)

The Verband Deutscher Elektrotechniker, having offered a prize of £15 for a description of the best type of non-exchangeable cut-outs, about sixty essays were sent in, and the prize was awarded to that by Mr. Rittershaussen of Amsterdam.

The cut-outs described in the essay are of the usual type, consisting of lead formed with thick ends for attachment, and a thin centre portion of the section calculated for the particular current. Each cut-out is held by a pair of studs with hexagonal nuts and washers of the usual form, and the cut-out itself is provided with a slot at each end, one slot being at right angles to the other. According to German practice, the size of the studs for cut-outs of 30 amperes, 40 amperes, and 50 amperes are all $\frac{1}{2}$ inch diameter, and the distance between centres is in all cases the same, viz., $2\frac{3}{4}$ inches; it is therefore obvious that any of the three cut-outs may by accident be substituted for the others. The same holds good for the cut-outs for larger currents. In order to prevent this, the Author proposes to provide special screwed ferrules of various sizes, each ferrule provided with one or more cross-cuts at the top; the ferrule is then screwed tightly home on the stud by means of a special key. The slot in the cut-out is made to suit the ferrule, and in this way, without any special alteration to the present switch-boards, the cut-outs could be made non-exchangeable. This may be illustrated by considering the three cut-outs referred

to above. The ferrules for $\frac{1}{4}$ -inch studs would be made 11 millimetres (0.433 inch) in diameter. For the 30-ampere cut-out, such a ferrule would be put on each terminal stud; for the 40-ampere cut-outs, only one such ferrule would be used; while for the 50-ampere size, no ferrules would be used. The cut-outs could not therefore be exchanged by accident. A Table in the original gives the proposed dimensions for cut-outs up to 1,000 amperes.

E. R. D.

Effect of Temperature on Insulating Materials.

GEO. F. SEVER, A. MONELL and C. L. PERRY.

(Transactions of the American Institute of Electrical Engineers, 1896, p. 225.)

The tests herein described appear to have been undertaken with a view to ascertaining the comparative qualities of various insulating substances used in such electrical apparatus as generators, motors, transformers, and coils generally, subjected to considerable ranges of temperature at ordinary low voltages.

The testing device consisted of a glass cylinder containing an electric heating device, capable of easy regulation, and an arrangement for supporting the test-pieces: these latter were formed of brass cylinders covered with the insulating material to be tested and wound with copper wire, then placed in the glass cylinder so as to throw the tubes into an active electric circuit completed through the insulation, wire coil and a galvanometer. Surface leakage through a special device of two smaller coils was eliminated from the galvanometer circuit.

The substances tested fell into several classes, such as plain paper (40 specimens): plain cloth (20 specimens): oiled paper (14 tests): and oiled cloth (28 tests), or 102 in all. The general conclusions drawn include the following:—Paper is a better insulation, and withstands increase in temperature better than cloth, oiled paper or oiled cloth. Both paper and cloth have a maximum resistance, when first heated, at about 75° C., but the point of maximum resistance depends on the rate of increase in temperature. The curves for plain paper and cloth are of the same general form, the resistance—poor at first—rapidly decreasing whilst the moisture is being driven out, and reaching a minimum at about 40° C. Then it rises rapidly to a maximum as stated at about 75° C.; after that falling equally to a second minimum on destruction at 150° C. or thereabouts.

Subsequent discussion upon this Paper by members of the Institute showed considerable divergence of opinion as to whether the tests thus carried out were trustworthy; and further, a written communication upon the subject from Mr. C. E. Skinner gives results of tests carried out with an apparatus which he describes. These tests (made on actual completed appliances, in some cases)

show quite opposite results to those of the present Authors; but the difference—as pointed out in the discussion—is largely due to the varied conditions employed, and must not be considered to imply contradictory deductions.

F. B. L.

Measurement of Power in Alternating Circuits.

DUGALD C. JACKSON.

(The Electrical World, New York, vol. xxviii., 1896, p. 351.)

In this article the Author deals more especially with watt-meter measurements in two- and three-phase circuits, the main idea being to reduce the number of separate readings to a minimum. Non-inductive watt-meters are of course essential, and these can now be readily obtained.

In two-phase systems the method to be followed is simple, and merely involves the taking simultaneously of independent watt-meter readings in each circuit. It is seldom the case that an exact balance between the circuits can be relied upon, otherwise a single watt-meter might be employed, the current coil being placed in the common wire (when a common return is employed) and readings taken in rapid succession with the pressure-coil connected alternately with each outside wire. The sum of the readings will give the total power.

With three-phase systems, three watt-meters may be employed, the sum of the readings being the total power in the system. Various precautions and conditions affecting this general rule are, however, detailed by the Author, more particularly with regard to Δ or mesh-connected apparatus. He also discusses the conditions under which two watt-meters and also a single one may be used to measure the power in a three-phase system. One watt-meter may be used in a balanced circuit by an arrangement similar to that described for two-phase system, but the lag must be the same for all the coils, and the load uniformly distributed.

This condition, however, is not practically realizable, so that the two-watt-meter method proves usually to be the most convenient and best. The current coil of each is put into one of the outside wires, and the pressure-coil between the respective outside and the third or inner. The readings are then added to give the total power, and are entirely independent of balance or current lag. The conditions to be fulfilled are these: when the mesh-connection is used, the algebraic sum of the instantaneous pressures between the line wires must be equal to zero; when the star-connection is employed, the algebraic sum of the currents must similarly be equal to zero. Also, if the equivalent current lag is more than 60° , the difference between, not the sum of, the two readings will give the total power.

F. B. L.

Iron for Transformer Plates.

(The Electrical Engineer, New York, vol. xxii., 1896, p. 497.)

The Author deals with reduction of the loss of energy due to hysteresis in the cores of transformers or in dynamos having iron cores.

It has been known for some years that this loss, in annealed iron cores which become heated in use, increases with time. This increase in hysteresis is specially marked in transformers as now ordinarily constructed. The Author states that if the heating of the iron could be prevented, the increase in the hysteresis would not occur, but it is commercially impossible to prevent the heating. The following figures as to the magnitude of the effect are given. An average fifty-light transformer, such as would be required to light a large sized dwelling house, has an iron-loss when new of about 55 watts.

This hysteresis loss increases in a comparatively short time to about 75 watts, and after extended use frequently increases by 100 per cent. to 110 watts. The first increase of 40 per cent. makes a difference in the average efficiency of the transformer of $3\frac{1}{2}$ per cent. on the load assumed by the Author.

The Author proceeds to value this loss to the Central Station, and concludes that it would amount to about £90 per annum in a 10,000 light station, when the energy is charged at $\frac{1}{2}d.$ per kilo-watt-hour. Hitherto attempts have been made to prevent this increase core loss by using a purer iron, as free as possible from all foreign substances. The Author states that Mr. John F. Kelly of Pittsfield has discovered that the hysteresis growth can be prevented by using iron containing a foreign substance such as silicon in suitable proportions. One proportion suitable for attaining the object is 0.0235 per cent. of silicon, the other parts being commercially pure iron. This amount of silicon is considerably larger than that in the ordinary iron used for laminated cores. The Author states that the abnormal amount of silicon does not increase the hysteresis loss in perfectly annealed samples when new, and also prevents the hysteresis increasing at the temperatures to which the transformers are subjected when in use.

R. W. W.*On the Use of Bare Wire for Resistance Coils. F. W. BURSTALL.*

(Philosophical Magazine, vol. xlvi., 1896, p. 209.)

The use of bare wire immersed in oil for resistance coils, suggested by Mr. E. H. Griffiths, has the advantage of enabling the temperature to be more accurately determined. Moreover, the wires do not heat so rapidly as when wound closely, and they can

at any time be annealed by the passage of a sufficiently strong current to render them red-hot for a few seconds. The Author has made a number of experiments with a view to determine the best method of arranging the coils. He winds them upon four serrated strips of mica held in position by brass crosses at either end. For the 100-ohm coil these strips are 15 centimetres long, and for the 1,000-ohm coil they are 25 centimetres long. He uses platinum silver alloy, having found manganin not sufficiently uniform in quality. The oil employed is a pure, heavy hydro-carbon, free from acids and alkalies, and without action on the wire.

G. J. B.

H.M.S. "Terrible."

(The Engineer, 15 January, 1897, p. 56.)

The conditions of the trial were (1) a run of thirty consecutive hours of continuous steaming at 5,000 I.H.P.; (2) a similar run at 18,000 HP.; and (3) a final run of eight hours, four of which being at 22,000 HP. and the remaining four at 25,000 HP. The first of these trials was successfully completed on the 6th August, the mean HP. actually realized being 5,110, this being generated by fourteen out of the twenty-eight Belleville boilers in the ship, the steam-pressure varying from 200 lbs. to 220 lbs. on the square inch. The engines ran at 64½ revolutions per minute, the mean speed of the ship being 13·4 knots.¹ The coal consumption averaged 2·27 lbs. per I.H.P. per hour. The second trial was completed on the 8th January, a few small repairs having been made, and the funnels heightened in the meantime. The mean HP. was 18,493, all the boilers being in use; the steam-pressure averaged 223½ lbs. per square inch. The engines ran at 102·7 revolutions per minute, the mean speed of the vessel being 21 knots. The coal consumption averaged 1·7 lbs. per I.H.P. per hour.

The third trial was carried out on the 9th January. During the first four hours the HP. developed was 25,572, the boiler-pressure being 229·6 lbs. on the square inch, the revolutions 112, and the speed 22·4 knots. During the second four hours the HP. was 22,282, the boiler-pressure 225 lbs. on the square inch, the revolutions 108·8. The coal consumption was not recorded.

A. W. B.

¹ This trial was made with excessive internal friction in the engines; the "Powerful" attained 14·3 knots with the same HP.—*Sec. Inst. C.E.*

The Russian Volunteer Steamship "Kherson."

(Engineering, 27 November, pp. 665 and 668; 11 December, p. 730; and 25 December, 1896, p. 800.)

The Russian volunteer fleet, to whose order this ship was made, was founded at the time of the Russo-Turkish war to supplement the Imperial Navy. It is supported by subscriptions, and is managed by a committee in Moscow, representing the Ministries of Finance, War Office, Imperial Navy, and the State Audit. None of the thirteen steamers composing the fleet have yet been engaged in actual war, but all are constructed with a view of being armed if necessary. All the ships have been built in England, and each is capable of carrying from 3,000 tons to 5,000 tons of cargo. The speeds are 19 knots in the case of four, and 13 knots in the case of the others. The fleet is regularly employed in trading between Odessa and Vladivostock, by way of the Suez Canal. The s.s. "Kherson," which is immediately under consideration, is the latest of this fleet. It was built by Messrs. R. and W. Hawthorn, Leslie and Co., Hebburn-on-Tyne, the engines being constructed by the same firm at St. Peters-on-Tyne. The ship is 493 feet long over all, 455 feet between perpendiculars, 54 feet 3 inches wide, and 37 feet 3 inches deep. When loaded to 24 feet draught her displacement is 10,255 tons. There is accommodation for seventy-four first-class passengers, fifty-nine second-class passengers, and 1,444 emigrants. The ship is built of mild steel on the longitudinal cellular-bottom principle, and holds about 900 tons of water ballast. There are ten water-tight bulkheads, extending to the upper deck. The three boiler-rooms each contain eight boilers, the stoking floors running fore and aft. The screw frame is a steel casting, and although the twin screws do not overlap, there is an aperture in the deadwood to prevent the disturbance of the race. The skin of the ship extends to the propeller, the frames being bent out to enclose the shafting. This avoids the necessity of shaft brackets.

The twin screws are driven by two sets of triple-expansion engines, with Marshall valve-gear. The cylinders of the main engines are 36 inches, 57 inches, and 92 inches in diameter, the stroke being 54 inches. They are supported on cast-iron A frames both back and front. The total cooling-surface of both condensers is 15,500 square feet. The two propellers, which are 17 feet 6 inches in diameter by 25 feet pitch, have four blades each. The pitch is adjustable by means of oval holes in the flanges of the blades. Steam is supplied to the main engines at a pressure of 160 lbs. per square inch by twenty-four Belleville boilers, supplied by Messrs. Maudslay, Sons, and Field, of London. The total grate-area is 1,132 square feet, and the total heating-surface 30,350 square feet. There are three funnels, each 9 feet 6 inches in diameter. Steam is generated at a pressure of 250 lbs., which is reduced to 160 lbs. per square inch before reaching the engines.

On her official twelve hours' trial trip, the "Kherson" attained a speed of 19·5 knots, with an I.H.P. of 13,307. The mean revolutions were 89·8.

A. P. H.

Car-Ferries of the Great Lakes of America.

(The Engineer, 5 February, 1897, p. 132.)

The vessels are constructed to accommodate a train of cars, and to cross the lakes with them both in summer and in winter, when they have to cut their own way through the thick ice. To make the ferries a success, it was necessary that the boats should be able to break down the ice. This has been accomplished by the adoption of the spoon-shaped bow, which bears down on the ice with nearly the whole weight of the steamer, and by placing a heavy propeller, worked by an independent engine at the bow, to help to demolish the mass of ice when too great to be crushed by the bow alone. The "St. Ignace" was the first steamer that succeeded in fulfilling these conditions, and started to run in 1889 in the Straits of Mackinac, between Lakes Michigan and Huron. She is 215 feet long, 52 feet beam, with a gross tonnage of 1,199, and is constructed to carry twelve freight-cars.

The second steamer, the "St. Marie," was added in 1893, and is 302 feet long, 51 feet 6 inches beam, and 24 feet deep, having a gross tonnage of 1,357. There is a propeller at each end, the forward one 10 feet 6 inches in diameter, driven by a compound engine; the after one is 12 feet in diameter. The hull is of wood sheathed with steel, and of very heavy construction; she carries eighteen cars on two tracks. Similar boats cross both Lakes Michigan and Erie on various routes.

A. W. B.

The New Car-Ferry "Pere Marquette."

(The American Engineer, February, 1897, p. 45.)

This vessel is for service on Lake Michigan, between Manitowoc and Ludington, a distance of 53 miles. It is 350 feet long, 56 feet beam, depth below main deck 19½ feet and 36 feet 3 inches deep from upper deck to floor. It has four tracks, and can carry thirty cars, weighing, when loaded, 1,350 tons. Carrying this load and 200 tons of fuel in addition the draught is 14 feet. The weight of steel in hull is 2,700 tons. Twin-screws, 11 feet diameter, are driven by two compound engines, with 27-inch, and 56-inch cylinders and 36-inch stroke. The I.H.P. is 3,500, and the speed 13 knots. Four cylindrical boilers supply steam at 130 lbs. pressure. There is cabin accommodation for twenty-five passengers.

S. W. B.

Electric Steering Gear.

(Elektrotechnische Zeitschrift, 1897, p. 66. 6 Figs.)

The Union Elektricitäts Gesellschaft have brought out a new type of electric steering gear designed by Mr. J. A. Essberger. The figures in the original text represent one of these apparatus in a German battleship.

The mechanism consists of two six-pole motors upon the same shaft which carries in the centre of its length a set of planet wheels. At the stern end of the shaft is fixed a worm which gears with two worm-wheels on vertical shafts, each shaft carrying a rope drum; a rope passes round these drums and guide-pulleys and actuates the rudder. The motors are arranged to rotate in opposite directions, and so long as they revolve at the same speed the planet gear has no turning effect upon the worm shaft; but as soon as the speeds of the motors differ the shaft revolves in one or other direction.

The winding of the motors is carried out in various ways, and the armatures may be connected either in series or in parallel. In the first case, the relative speeds of the motors are altered by switching a resistance in parallel with one of them. If the field magnet be constantly excited then the armature of the motor subject to the braking action will work as a generator. In the second arrangement the armatures are coupled in parallel, while the field coils are connected in series. Regulation is effected by switching resistance in parallel with the field coils of that motor the speed of which is to be raised.

Motors were designed which took only 1 per cent. of the current for the excitation of the field coils. The action is so free from jerks that the mechanism can be supplied with current by the lighting dynamo without prejudicial results. In order to hold the rudder in position an average current of 1 ampere is sufficient, and each motor is capable of developing 50 HP.

The object of the article is to show the great superiority of the mechanism described over that of a single motor which must be started and reversed continually, in which case very large currents must be broken. It is claimed that the mechanism is eminently suited for electric lifts.

E. R. D.

Canet's Quick-firing Field-Guns.

(Engineering, 27 November, p. 668; 4 December, p. 696; 11 December, p. 726; 18 December, p. 766; 25 December, p. 801, 1896.)

These guns, which have been produced by Mr. G. Canet, of the Forges et Chantiers de la Méditerranée, embody novel construction both in the breech mechanism of the gun itself and in the method of taking up the recoil. The different types of breech mechanism

aim at combining simplicity with certainty of action. In the first type a cylindrical breech block, with alternate screwed and plain segments, fitting into a corresponding seating, is opened and closed by the movement of a lever in a vertical plane through 90° . The block is swung outwards on a hinge for reloading. The percussion lock is set automatically, the main spring being drawn back during the rotation of the breech block. In the second type the breech block is conical, with interrupted thread, and can be rapidly rotated by a lever moving in a horizontal plane through mitre-gearing. A repetition firing device is employed, by which, in case of a missfire, the fuse can be struck several times. The third type is of a very original construction. The two vertical and parallel sides of the block chamber are cut with semicircular grooves, in which the block swings through 90° on a horizontal axis. When open, the curved back of the block forms a continuation of the bore of the gun to assist in loading. This movement is accomplished by a lever moving in a vertical plane. The firing device, as before, is placed in the block.

The apparatus for taking up the recoil is intended to overcome the objections to all previous mechanisms of this nature. These may be classed as, first, those in which the gun is rigid with the carriage, the recoil of the latter being limited or prevented; second, those in which the carriage is rigidly fixed, and the gun is connected thereto by some yielding device. In the first system, in which the trail is anchored to the ground, the tendency of the recoil is to lift the carriage, while at the same time the reaction of the rotation imparted to the projectile by the rifling twists the carriage in the opposite direction. Thus the gun-carriage is subjected to a series of oscillations around the fixed trail. This can be to some extent remedied by adding dead weight, which, however, renders the gun less portable. The objection to the second system is that only the weight of the gun is utilized to take up the recoil, thus throwing a great strain upon the brake mechanism. In the Canet system the tendency to lift is suppressed, while the weight both of the gun and of the carriage is available to take up the recoil. The trail is telescopic, the action of the recoil being to drive one section within the other, which is resisted by a hydro-pneumatic brake. The energy so absorbed at once returns the gun into firing position. To the rearmost point of the trail is fixed an anchor plate, which becomes firmly embedded in the ground after the first shot.

A. P. H.

Wind-Pressures in the St. Louis Tornado, 1896. T. BAIER.

(Proceedings of the American Society of Civil Engineers, January, 1897, p. 55.)

The destruction of several structures, viz., the upper portion of the masonry approach of the St. Louis Bridge, a tall chimney, a grain elevator and other buildings, gave the Author an opportunity

to determine by computation the pressure per square foot with which the tornado must at least have acted upon them, and finds it ranging from 45 to 90 lbs. He comes to the conclusion that buildings should be constructed to resist generally a pressure of 40 lbs. with a provision of 50 lbs. in upper storeys. The relation between the flow of air and the pressure is $P = c v^2$, v being velocity in miles per hour, and former experiments have determined the constant c at 0.004 on an average; but experiments by C. F. Marvin on Mount Washington, and by S. P. Langley (*Smithsonian Contribution to Knowledge*, No. 884), show that rapid and intense fluctuations occur of which former experiments only recognise the average. Kernot (*Engineering Record*, February 10, 1894) shows by experiment a marked difference in pressure if other buildings are near, and Irminger (*Engineering News*, February 14, 1895) shows the importance of the suction on leeward surfaces of buildings. H. C. Frankenfield's Report on the Tornado of 1896 in the *Monthly Weather Review*, and also W. L. Moore's data of 368 tornados occurring between 1889 and 1896 (*Annual Data Volume of the Weather Bureau for 1896*) are referred to.

M. A. E.

The Lightest Substance known and its Uses. FROITZHEIM.

(*Verhandlungen des Vereins für Eisenbahnkunde*, 1896, p. 58.)

The Author states that the lightest substance known is the pith of the sunflower with a specific gravity 0.028, whilst elder-pith—hitherto recognised as the lightest substance—has a specific gravity of 0.09, reindeer's hair 0.1, and cork 0.24. The sunflower is cultivated to a large extent in Central Russia, and the uses to which its various parts are converted are fully described, and the discovery of the lightness of the pith has essentially increased the commercial value of the plant. For saving appliances at sea, cork with a buoyancy of 1 to 5, or reindeer's hair with one of 1 to 10, has been used, whilst the pith of the sunflower has a buoyancy of 1 to 35. The Author suggests several cases in which this pith might be advantageously used in the construction of boats and life-saving appliances, and states that a sufficient quantity can be worn on the person without any inconvenience which will ensure perfect safety in case of immersion.

J. A. T.

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TO THE

M I N U T E S O F P R O C E E D I N G S ,

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Fig: 4.

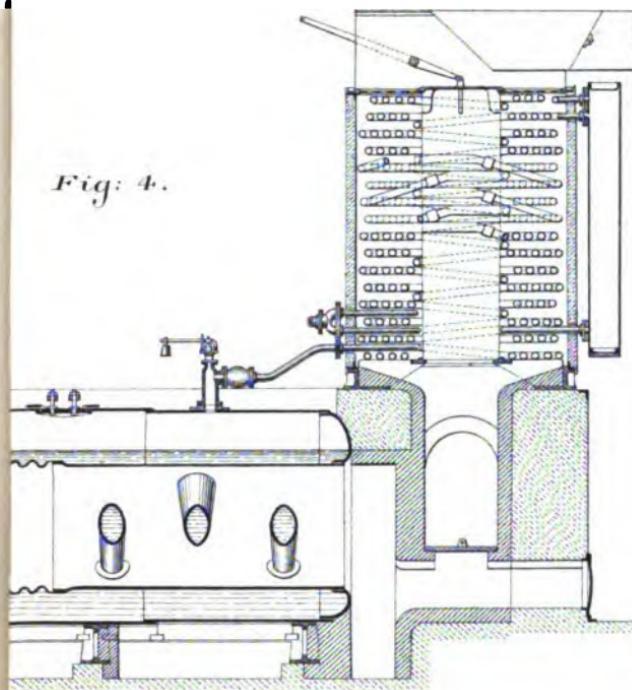


Fig: 64.

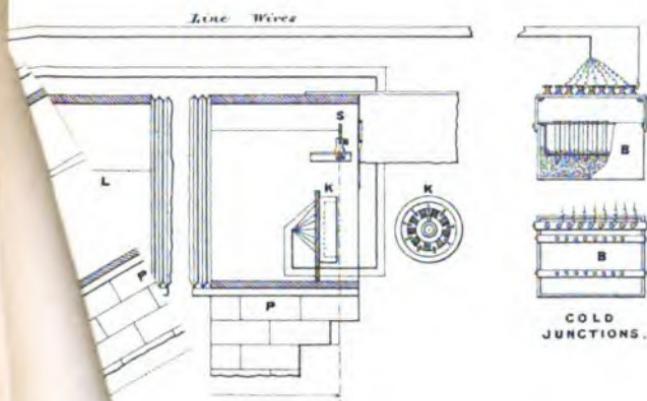
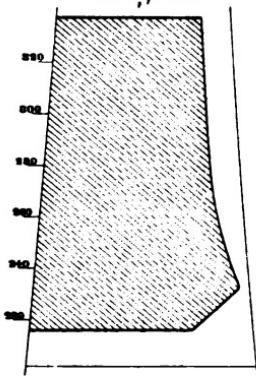


Fig: 49.



Load Series 220
Trial No. 220
Diameter of cylinder 180-3
Initial pressure 181
Steam per H.P. hr 20-08

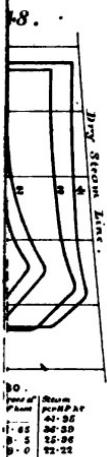
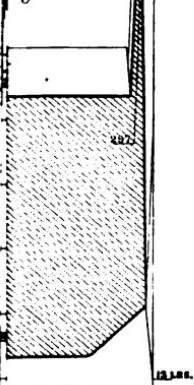
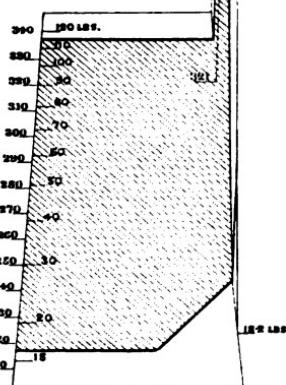


Fig: 55.



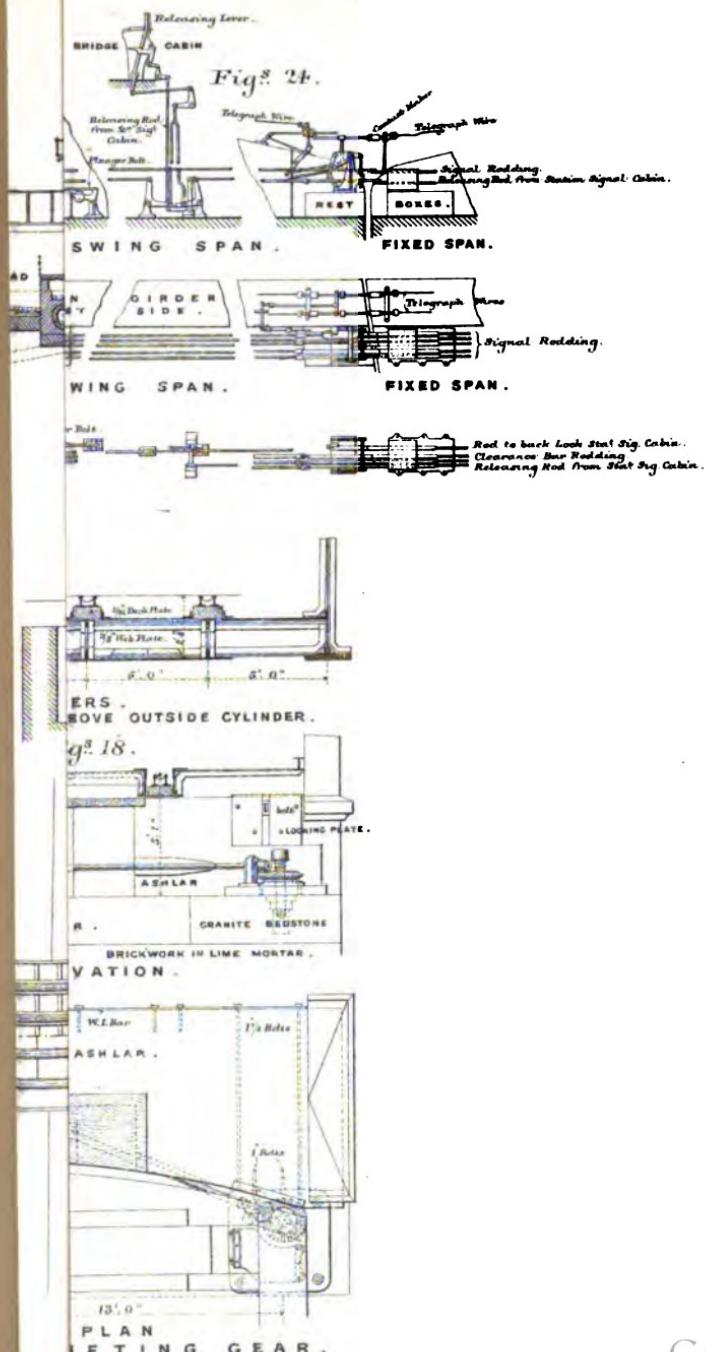
Time... 220
Loc... 18
Superheat 320-4
Pressure 20-45
Steam per H.P. hr 20-08

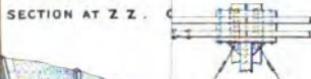
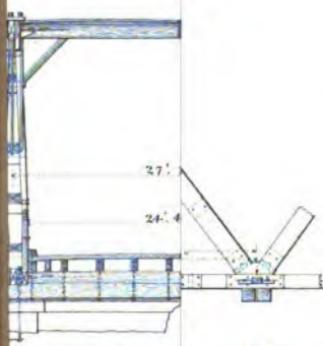
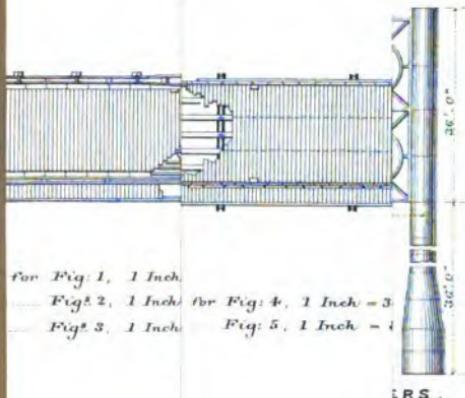
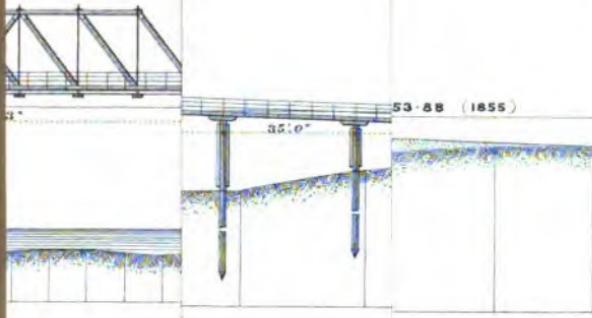
Fig: 56.



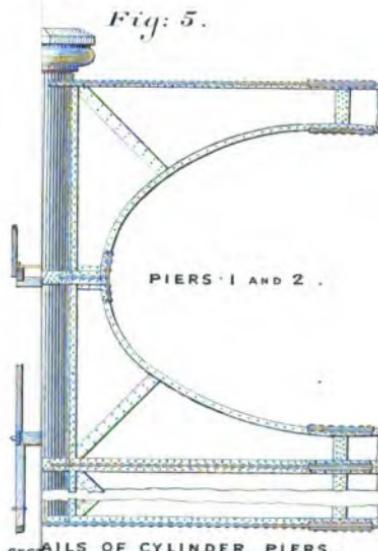
Time... 6
Loc... 32
Superheat 320
Steam 17-04
Initial pressure 114-1

PLATE 4.

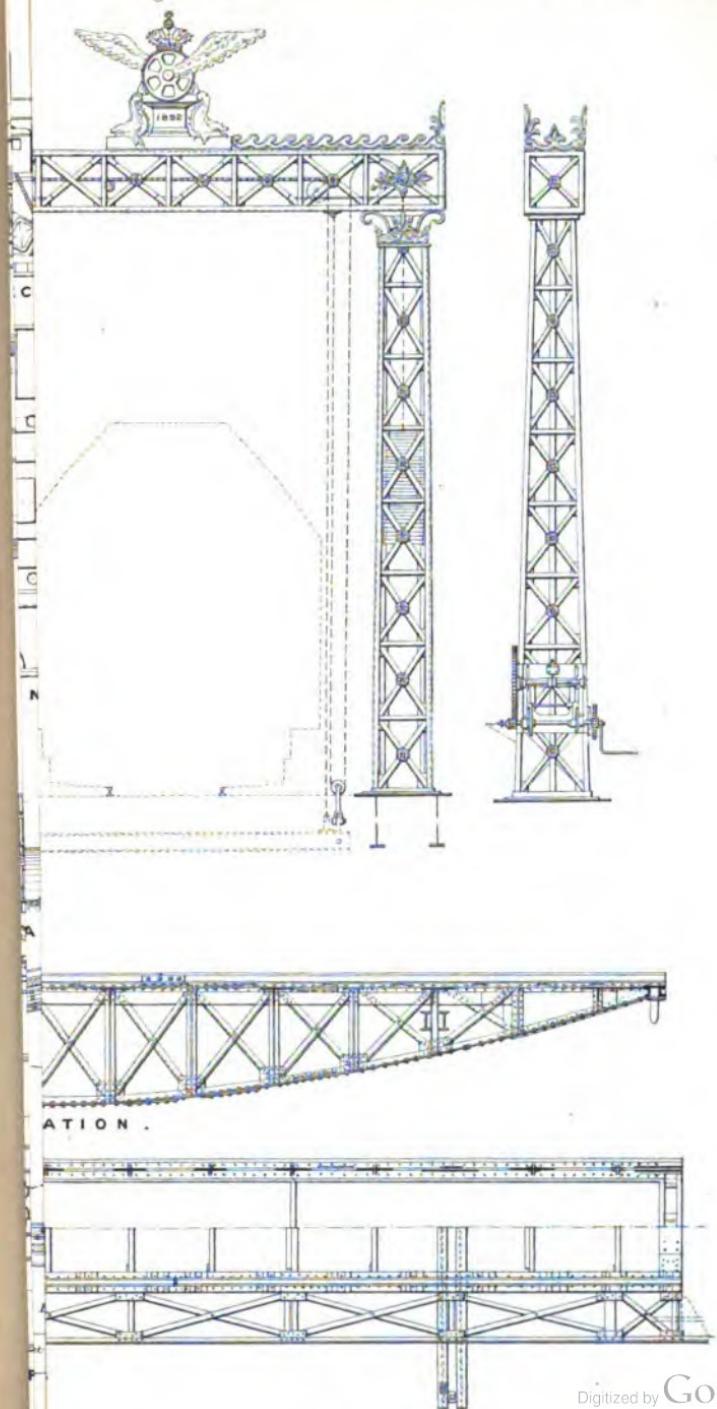




PLAN AT ABUTME

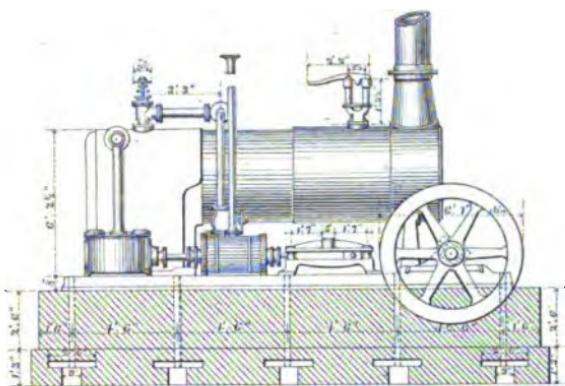


KELL & SON, LITH. 40 KING'S COVENT GARDEN.

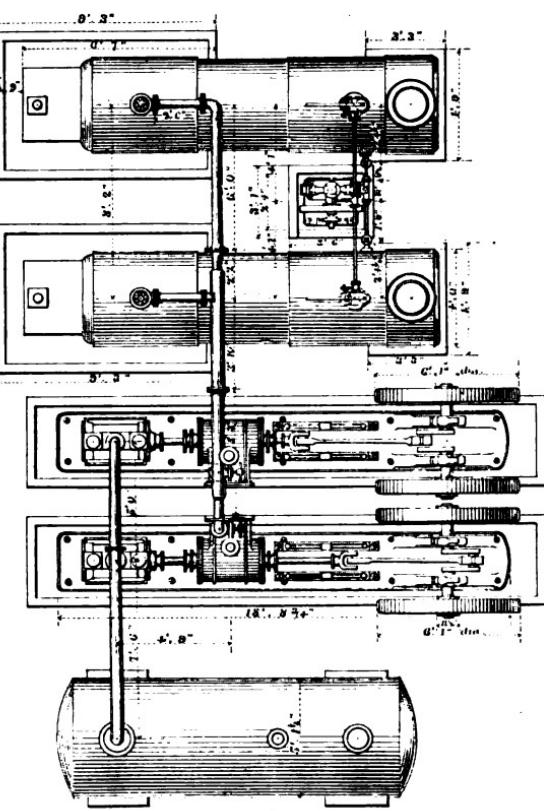


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PLATE 7.



SIDE ELEVATION.



PLAN.

Scale for Fig. 29 - $\frac{1}{8}^{\text{th}}$ Inch to 1 Foot.

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PLATE 8.



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